A SEDIMENTOLOGICAL AND PALAEOGEOGRAPHICAL STUDY OF THE NAMURIAN 'ROUGH ROCK' IN THE SOUTHERN PENNINES

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C O N T E N T S

ABSTRACT

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SECTION 1. THE SETTING

ABSTRACT

The Rough Rock is the highest sandstone in the Namurian, being overlain by the _Gastrioceras subcrenatum_ Marine Band, which marks the junction between the Namurian and Westphalian in north-west Europe, and its occurrence in the southern Pennines forms the subject of this study.

The delineation of the Rough Rock of this study is discussed, and the problems of correlation and the results of previous studies are detailed. It is shown that much of the previous research is invalidated by mis-correlation with the overlying Westphalian sandstones and the contemporary hypotheses of Millstone Grit derivation.

The Rough Rock is divided into several lithofacies, each indicative of a local depositional environment, and an analysis is made of their local and regional distribution. By combining this information with measurements of cross-stratal azimuths, a broad picture of fluviatile deposition locally controlled by syntectonic features is obtained.

Finally the combined effect of differential subsidence between Gulf and Block developments and contemporary movement along Charnian, Malvernian and Church Stretton structural features, on sedimentation and palaeogeography, is displayed.

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Section 1

THE SETTING

Chapter 1

Introduction

The Rough Rock is the highest sandstone in the Namurian succession of Northern and Midland England, being placed by convention in the upper Yeadonian, G1b or C division of the Namurian (Fig.1), its outcrop lying within an area of over 4,000 square miles. It occurs immediately below the junction between the Westphalian and the Namurian and lies between two other prominent sandstones, the Namurian Holcombe Brook Grit and the Westphalian Woodhead Hill Rock, which would allow an extension of research, at a later date, on sandstones in many ways similar to the Rough Rock. Below the former, coals are rare, and the faunal horizons are goniatite-bearing with occasional lingula horizons, and sandstones can usually be traced over fairly large areas. Above the latter, coals are prominent, faunal horizons, where marine, are usually separated by greater thicknesses of strata, and non-marine bivalve horizons are frequent, whilst sandstones are usually localised and cannot be correlated over large areas.

It was proposed to study the Rough Rock over a restricted area, with the intention of examining the effect, if any, of the Basement/Carboniferous Limestone surface and large-scale structures on the depositional history of the Rough Rock. In the Namurian, 'Gulf' and 'Block' facies had been observed (Falcon & Kent 1960, Kent 1966), while in the Westphalian the splitting and reuniting of coal seams, together with the apparent preference of washouts to follow synclinal axes (Cope pers. comm. concerning the Potteries Coalfield), pointed to some type of structural control. Bluck (1961) in the South Wales Coalfield, at an horizon slightly above that of the Rough Rock in the Central Province, observed evidence for currents flowing into the central part of the present South Wales Syncline.

The need to include the Derbyshire Dome and the north-south aligned Goyt Trough or Syncline, and Kettleshume Anticline to the west, was obvious, but it was soon apparent that restriction of the study to the western side of the Pennines would limit the east-west extent of the area to a maximum of only 15 miles. The area was, therefore, extended to cover both sides of the Pennines in order to make the east-west component similar to the north-south one.

At this stage, it will suffice to define the area studied, its topography and structure, as the more detailed aims, and the reasons for setting limits to the area are dealt with later.

The area studied falls within four administrative areas: North Staffordshire, east Cheshire, the south-western part of the West Riding of Yorkshire, and west Derbyshire (Fig.2). The northern boundary is that of Grid-Line northing 390 between Marple and Sheffield; the western, southern and eastern limits are marked by the outcrop of the formation. In the west, this approximates to the line of the Red Rock Fault, between Stockport and Mow Cop, which throws the Triassic of the Cheshire Plain against the Carboniferous of the southern Pennines. The southern limit, though approaching the boundary between the

Carboniferous and the Triassic, is irregular, owing to the Triassic infilling valleys eroded into the Carboniferous, and the broad, southerly-plunging Potteries syncline. The eastern boundary is the almost north-south aligned junction of the Namurian and Westphalian between Derby and Sheffield. The outcrop of the Rough Rock occurs within an area of 900 square miles, and the length of the outcrop is approximately 170 miles (Fig.2).

The area including the outcrop covered by this investigation is covered by Ordnance Survey one-inch sheets 101 (Manchester), 110 (Stoke-on-Trent), 111 (Buxton and Matlock), 120 (Derby), and the 'Peak District' Tourist Map. Geological Survey (New Series) one-inch sheets covering the area are 98 (Stockport), 99 (Chapel-en-le-Frith), 100 (Sheffield), 110 (Macclesfield), 111 (Buxton), 112 (Chesterfield), 123 (Stoke-on-Trent, in preparation), 124 (Ashbourne, out of print), and 125 (Derby, in preparation). Parts of the area are covered by published six-inch Geological Survey sheets.

Structurally, the area is fairly complex, the folds in places being moderately tight, and the trends when taken for the whole area almost box the compass (see Fig.3).

The area is dominated by the Derbyshire Dome, a limestone massif, largely surrounded by outward-dipping reef limestones, having a broad flat axial region trending north-south near its western margin, and a complex series of folds to the east. Movement occurred throughout Lower Carboniferous times, in some cases the effects of several phases being superimposed.

To the west of the Derbyshire Dome, the folds exhibit a general north-south trend, the Goyt Trough running from Hayfield in the north to the Roches in the south, possibly extending as far as the Cheadle Basin near the southern boundary. The complementary tight Kettleshume anticline to the west of the Goyt Trough runs from south of Disley in the north to north of Wincle in the south, where it dies out in a much-faulted area; a more southerly representative of this structure may be the faulted anticline to the east of the Staffalong Syncline and to the south of the area in the Chartley Axis. Shallow folds to the west of the Kettleshume Anticline occur, having a north-west/south-east trend, namely the Poynton Syncline and the Bollington Anticline. In the south-west, there occurs a fan-shaped arrangement of folds centred around the Potteries Coalfield. The north-south trend of the U-shaped Shaffalong Syncline bends round to the north, giving a north-west/south-east trend. The Lask Edge anticline, to the west, parallels this trend in the south, though trending nearly north-south in the north. To the west of the Lask Edge anticline, which has dips of up to 80° on its limbs, lies the plunging asymmetric Potteries Syncline trending north-east/south-west, having dips in the order of 15° and 75° on the east and west limbs respectively, in the north part of the fold; further south these dips diminish. The Potteries Syncline is followed to the west by the tight Mow Cop Anticline, trending north-east/south-west, having steep dips of up to 75° on both limbs. The apex of the triangular arrangement of folds is near Bosley, where it dies out in an area of parallel, north-south trending en echelon folds.

In the north, the fold trend swings round from north-south to east-west, giving the Edale Anticline and the Kinderscout Syncline running nearly parallel to the northern boundary of the Carboniferous Limestone. Moving eastwards, the trend changes to north-west/south-east giving the Norton-Ridgeway and Brimington Anticlines, with to the north, the Don Monocline, trending north-east/south-west, dying out near Fulwood, south-east of Sheffield.

To the east of the Derbyshire Dome, the most prominent fold is the Ashover-Crich Anticline, running from Beeley in the north to Ripley in the south, with a north-west/south-east trend. South of Ashover, the trend swings round to north-south; it finally dies out below the Coal Measures east of Crich with a north-west/south-east trend. Most of the minor folds to the east have a north-south trend, though between Chesterfield and Mansfield the Brimington Anticline has a north-west/south-east trend, which swings round south of Mansfield to an east-west trend and is termed the Hardstoft-Mansfield Anticline.

Faulting over the whole area generally runs parallel to the trend of the folds or runs perpendicularly across them; the latter usually being wrench faults. By far the largest fault is the Red Rock Fault which, according to the Geological Survey, has a throw near Astbury of up to 7000'. Most of the folds die out in heavily faulted zones, and it is thought that the folds and faults are probably broadly contemporaneous. According to the Geological Survey (Evans et al. 1968) the Mow Cop fault is older, as it is folded around the nose of the Mow

Cop Anticline, this is the only example of faulting being older than folding. Many of the faults give evidence of post-Triassic movement.

Over most of the area studied, the Rough Rock does not form a particularly strong topographical feature, much stronger features being formed by sandstones below. In the southern part of the area the Rough Rock is at a low elevation. At Coxhead it is at only 400' O.D. and at Wall Grange it is at only 600' O.D., slowly rising to the north to become 900' O.D. at Holymoorside and 800-900' O.D. in the Biddulph area. Over most of these southern areas it barely forms a feature; south of Chatsworth, the Rough Rock thins considerably and has no visible effect on the landscape until south of Ambergate where it thickens to over 80' giving a rounded scarp. Over the North Staffordshire area a similar state of affairs persists, there being no bold scarp, except on the eastern limb of the Potteries Syncline where, in places, tor-like prominences stand up above a rather weak feature. In the Goldsitch area, and on the western limb of the Shaffalong and Potteries Syncline the feature is no more than a small ripple on the surface. To the north of Chatsworth and Danebower the sharp scarp topography is found. The elevation is generally above 1000' O.D., the highest point being 1700' O.D. near the Cat and Fiddle Inn. From this point looking northwards one can observe the scarp of the Rough Rock as far as Rowarth, the scarps and dip-slopes of Hoo Moor, Ladder Edge, Cracken Edge, Whaley Moor, Lantern Pike, Mellor and Cown Edge being especially prominent, while to the south one can see the dip slopes of Reeve Edge and Danebower. Even in this area the scarp of the Rough Rock may die out altogether as between Ladder Edge and Goyts Lane, and south of Disley (Plates 1,2,3,4).

In the Sheffield area, although the scarps are not as prominent as in the Goyt Trough, they form bold features such as Flask Edge and Rud Hill.

The most striking aspect of Rough Rock topography is man-made. Over the whole area, quarries have been opened, forming stark gashes in the otherwise rough moorland country. At Cracken Edge the quarries are almost continuous from Chinley Churn to Birch Vale - a distance of two miles. In general the quarries occur at regular intervals.

The area is easily accessible, being well served by tarmacadamed roads. No point on the outcrop is further than 2 kms. from a serviced road. With most of the area being situated within the Peak District National Park, footpaths are abundant and there is little difficulty in gaining access to outcrops. Access to outcrops was prohibited during the Foot and Mouth Epidemic (November-May 1967/1968); also, in certain cases access to outcrops was not granted by landowners who thought that the information gained might fall into the hands of industrial concerns, which was especially the case in areas where quarries were expanding and where construction of reservoirs might occur.

Exposure over most of the area was fairly good, in between the sections taken from quarries and dip and scarp slope streams were numerous small exposures. Only the very top of the Rough Rock and the seat-earth, coal and mudstone shales below Gastrioceras subcrenatum were poorly exposed.

Chapter 2

Background to Research

Introduction

Sedimentological investigations of Namurian rocks must depend for their success on accurate stratigraphical correlation. Reference must be made to a chronological sequence of faunal datum planes, characterised, in the area studied, by marine faunas. These allow lateral correlation of events and features to be established or rejected, and palaeogeographic maps to be constructed.

The sediments described in this thesis are sandstones from the uppermost cyclothem of the Namurian sequence in the southern part of the Central Province, where that Province is defined as that area "....between the Welsh-Mercian ridge and an east-west narrow ridge through the Isle of Man to the Settle District." (Trotter, 1952). The limits of the Province have been slightly altered since the palaeographic map produced by Wills (1951). The limits and facies changes of sandstones and the changing assemblages of marine bands can now be more accurately portrayed, (Calver (1969) and Ramsbottom (Pers. Commun.)).

Rough Rock: Stratigraphical Position and Name (Fig.1 & Enc.1)

The Rough Rock has been placed at various stratigraphical horizons up to the latter half of the 1960's. With the publication of the Chesterfield (112), Chapel-en-le-Frith (99) and Macclesfield (110) Geological Survey Sheets in 1967-68, the position of the sandstone has been fixed between recognisable horizons over the greater part of the Pennine area. The recognition of these horizons had been made possible by the work of Bisat in his paper "Carboniferous Goniatites of the North of England and their Zones" (Bisat, 1924), in which the genus Gastrioceras was shown to include the species G. cancellatum, crenulatum, crencellatum and cumbriense, certain species being confined to thin marine bands in the Upper Millstone Grit, a feature first appreciated by Hind (1909). The species G. subcrenatum had been recognised earlier and is usually credited to Schlotheim (1820), though much argument still surrounds this issue (Ramsbottom and Calver, 1962).

Prior to this pioneer work, mapping was carried out by Hull and Green (1864, 1866), Pocock (1906), Barrow (1903), Walcot Gibson (1905a, 1905b, 1913), Green (1878, 1887), and others in conjunction with them, using for correlation only lithological and occasional palaeontological evidence. The maps and papers produced placed the Rough Rock, as we know it today, at levels within their Coal Measures, below the junction of, and within their Millstone Grit, e.g. Buxton Geological Sheet 81 N.W. 1842, Hull and Green 1864. Although the name Rough Rock was first used by Prestwich (1840) in Coalbrook dale for a Coal Measures sandstone, adapted by Binney (1841) for the 36' of grit at the base of the Lower Coal Measures, Hull (1862) for the highest sandstone of the Millstone Grit, and retained by Hull and Green (1864) for the same sandstone placed at the top of the Millstone Grit, the terms First Grit, and Topmost Grit; first used by Hull and Green (1857), were still used in conjunction with it as an aid to mapping. The numerical name appears to have been the fundamental cause of the various levels to which the Rough Rock was assigned.

The numerical system had been in use since 1811a (Farey), although with a reverse sequence, (Farey 1811b), the highest number being at the top of the Millstone Grit. In the North Staffordshire area Farey placed the Rough Rock in the Lower Coal Measures as did Binney thirty years later. The Haslingden Flags were then termed the Second Grit (Hull & Green, 1864, p.246 and Walcot Gibson, 1905, p.35). This system proved to be impractical and misleading.

In general, the numbering commenced at the first sandstone below the last economic coal, and the top of it was taken to be the Coal Measures/Millstone Grit boundary, the sandstones being numbered accordingly as the succession was descended. Only in Lancashire was a coarse sandstone included within the Coal Measures, this being the Woodhead Hill Rock. The Rough Rock of today was thus termed the First Grit, and the Haslingden Flags the Second Grit; the latter being an easily mappable and correlatable horizon owing to its flaggy lithology and included shale. In this area correlation was, therefore, fairly accurate. This is also true for the eastern part of the Potteries area, though the Woodhead Hill Rock is locally absent, and the Haslingden Flags completely absent. In the Goyt Trough and East Cheshire, the Woodhead Hill Rock was mistaken for the Rough Rock, owing to the flaggy development of the underlying true Rough Rock, which was, therefore, called the Second Grit or Haslingden Flags; the true Haslingden Flags, where present, being mistaken for the Lower Haslingden Flags of

Lancashire, and included in the Second Grit.

This system of lithological comparison caused different sandstones to be given the same name. It also caused the boundary between the Coal Measures/Millstone Grit and the Millstone Grit/"Yoredale Rocks" to vary in position according to the presence or absence of sandstone in different areas. In the extreme case of the western limb of the Potteries Syncline, the Millstone Grit was, on this basis, only 170' thick. Both the First and Third Grits are present in the north, therefore the Coal Measures/Millstone Grit and the Millstone Grit/ "Yoredale Rocks" boundaries are at the top and base of the grits, respectively. In the south, near Mow Cop, the First Grit had, according to Gibson (1905a), died out; thus the boundaries were placed at the top and base of the Third Grit.

Green et al. had recognised the dangers with this system:-

"Now the sandstone beds never keep for long the same thickness, but are wedge-shaped and dove-tail into the shales, so that thick masses of sandstone are often lost altogether..... and hence lines which merely separate sandstones from shale are often far from true geological horizons." (Green et al. 1887, p.7).

Following the publication of Bisat's goniatite zones, there was a rapid increase in the research on the Millstone Grit, though mostly giving only new fossil localities and details of stratigraphical position. In many cases, Bisat's zones were misused, owing to the poor identification of the goniatites. Hester (1932) in North Staffordshire mistook the Gastrioceras listeri horizon for the G. subcrenatum horizon; W.B. Wright (1926a) in Lancashire attempted to demonstrate stratigraphical diachronism on the basis of similar species of Gastrioceras; and W.B. Wright (1926b) incorrectly named the marine bands, assigning G. listeri to the G. subcrenatum and G. cumbriense horizons of Lancashire.

In 1927, the Namurian - a time division as opposed to the Millstone Grit lithological division - was defined by Jongmans (1928) as occurring between the base of Gastrioceras subcrenatum Marine Band (at top), and the top of Glyphioceras spirale Zone (at base). The base later altered to the Eumorphoceras pseudobilingue Marine Band (Jongmans & Gothan, 1937). This division was internationally agreed at the Heerlen Congress, and all the zones were verified by Hudson (1945). In Britain the name 'Millstone Grits' is still retained as a lithological division of the Namurian and usually refers to the sequence of shales and sandstones in the Reticuloceras and Gastrioceras stages of the Namurian.

By 1935 the Rough Rock had been correctly correlated north of Stockport and Sheffield. The area south of Stockport had been correlated by 1954 mainly through the work of F.W. Cope, though Broadhurst (in Eager et al. 1959) still equated the Woodhead Hill Rock with the Rough Rock in the Hayfield area. Challinor (1929, 1930) placed the Rough Rock in the Middle Grits, and even after Bisat's identification of fossil material from Goldsitch Moss he failed to call the sandstone above it the Rough Rock, retaining the name Goldsitch Grit, a name he first used in 1921.

Cope (1946a) dealing with the contorted beds in the Upper Carboniferous of the southern Pennines gave localities for G. subcrenatum, G. cumbriense and G. cancellatum, thus proving the Rough Rock horizon as far south as the Roches. Cope (Pers. Comm. and unpublished work) had mapped most of the Goyt Trough and east Cheshire area proving the Rough Rock and its marker horizons, mis-correlation occurring only at Eccles Pike, Hayfield and around Macclesfield (assuming the Geological Survey to be correct at Eccles Pike and Macclesfield). The contorted beds have been proved a useful indicator of a marine band, a fact other workers have proved over a fairly wide geographical area (Smart and Frost, 1968; Williamson, 1953). In 1948a Cope observed faunal phases in the G. listeri marine band above the Bullion Mine of Lancashire, this fact being later applied by Potts (1960), Heptonstall (1964) and Broadhurst & Loring (1970) to the G. cancellatum band and by Haslam (1966) to the G. cumbriense band. Calver (1968) showed a geographical variation in the generic content of the G. subcrenatum band. Moving southwards, the Stoke-on-Trent area had also been covered, though this mainly verified earlier work. Cope (1948b) and Myers (1952a) proved the succession in the Timbersbrook and Stockton Brook boreholes respectively. Earp (1961) and Trotter (1954) gave the succession in the Ridgeway and Bowsey Wood boreholes, the latter showing the G. cancellatum marine band being separated from the Carboniferous Limestone by only a few feet of sandstone, evidence for faulting being absent; a similar state of affairs exists at Rhydymwyn in Flintshire. This leaves only the Mow Cop, Macclesfield and Shaffalong/Cheadle areas in doubt. In the latter, G. subcrenatum has been found at Wetley Rocks (Wilson

1962) Oakmoor (Edwards 1956) and near Shaffalong in situ by the author. G. cumbriense at Wall Grange (Cope in Myers 1952b; Wilson 1960) and G. cancellatum at Wall Grange (ibid.), Foxt (Morris 1969) and near Shaffalong by the author. Cope (1946b) on correlation of the Cheadle Coalfield observed the Rough Rock to be only 6' thick and the G. subcrenatum marine band to be absent though the associated contorted bed was still present. At Mow Cop the only evidence is the presence of "cancellate goniatites" in spoil heap material near to the presumed outcrop of the Rough Rock. Again in the Bollington area there are few outcrop data, correlation being governed by sub-surface and inferred data.

In the Sheffield area, Downie (1960) gave localities for the Rough Rock and the G. subcrenatum and G. cumbriense Marine Bands, at Blacka Moor, Dore.

South of Sheffield the thinning of the Rough Rock and absence in places together with the change from goniatite to linguloid facies of the G. subcrenatum band had caused the Crawshaw Sandstone to be termed Rough Rock. Before the publication of the 1" Geological Survey sheet for Chesterfield and the 6" Geological Survey sheets further south, numerous workers had attempted a correct correlation, though in very small areas. Stephens (1953) in the Ambergate area maintained that the Rough Rock had two leaves, the upper in fact being the Crawshaw Sandstone which died out to the north. This was possibly a biased observation attempting correlation with the Lancashire and Yorkshire area. The Ambergate area was corrected by Smart and Frost (1968) who observed G. subcrenatum between the two sandstones; though it was only a Lingula-fish band accompanied by a contorted bed. In the Holymoorside area, Smith (1967) observed the G. subcrenatum and G. cancellatum bands and found the Rough Rock below the former to be only 9" thick; 1 mile farther east he found the Rough Rock to be absent, though the G. subcrenatum band was still present. Near Derby, Eden (1954) working from a correlation in boreholes equated the Rough Rock with the Coxbench Grit, the overlying G. subcrenatum band being represented by a Lingula-fish assemblage. Eden's work was apparently not consulted by T.D. Ford (1968) who gave the Coxbench Grit as an equivalent of the Ashover Grit.

Moving to the flanks of the Central Pennines, correlation has been slow. In N.E. Wales, Wood (1936) on the goniatite zones of the area, gave localities for G. subcrenatum in the Abbey Mills Borehole, at Nant Felin Blwm and Trevor, G. cumbriense in the Abbey Mills Borehole, at Leeswood Hawarden and in the Terrig and Cegidog Rivers. The sandstone in between being the Lower Gwespyr Sandstone except at Trevor where it is the Aqueduct Grit. Bathurst et al. (1965) observed G. cancellatum below 20 ft. of yellow micaceous, ripple-marked sandstone containing cast of Stigmaria. at Ruby Brickworks, east of Halkyn Mountain. They correlated the sandstone with the Gwespyr Sandstone. Bisat (1940) observed the G. cancellatum band at Minera Mills near Wrexham and 9' below a further band with a new species, G. branneroides, the identification of the same species in the northern part of the

Warwickshire Coalfield (Ramsbottom 1954) led to the idea that this was a species confined to the flanking area. This was later rejected by Heptonstall (1964) who observed the species in the lowest part of the G. cancellatum horizon over a large area. The evidence along the southern flank is sparse, owing to the thick cover overlying the Upper Millstone Grit, which in places is absent altogether; Mitchell and Stubblefield (1945) failed to observe strata of Millstone Grit age. Two later boreholes, the Trent Valley (Stephenson and Mitchell, 1955), and the Whittington Heath (Mitchell, 1954), have proved the lower Gastrioceras zone of the Millstone Grit. In the former, G. subcrenatum, G. cumbriense and G. cancellatum were observed; in the latter, only G. cancellatum was proved. Other boreholes at Rugeley (Fair Oak) and further south are unreliable; the Fair Oak or West Hill Marine Band, usually taken to be Gastrioceras listeri could in fact be G. subcrenatum (Calver 1968).

In the Leicestershire coalfield possible representatives of the Rough Rock occur at Dawson's Rocks, and The Building, north of Hartshorn. This is based on the presence of Dunbarella sp. in the shales below the Triassic at Newbould Brick Works and G. subcrenatum in a borehole near Melbourne Reservoir (Mitchell and Stubblefield 1941, Horton and McAdam 1962).

By far the most important flank has been the eastern, where oil exploration boreholes have produced a large amount of closely located data. Early workers fell into the trap of mis-correlation, in the absence of the indicator, G. subcrenatum, since in south-west Derbyshire the marine band has a lingula facies. Lees & Tait (1946) and Falcon & Kent (1960) had equated the Rough Rock with the Crawshaw Sandstone. Brunstrom (1963) was the first to show a correct correlation in the East Midlands Oilfields, and this was later verified by Taylor & Howitt (1965) and Downing & Howitt (1969). The Rough Rock, as in South Derbyshire, varied in thickness and was associated over most of the area with lingula bands, though at Egmanton, Bothamsall, Colston Bassett and Langar, Gastrioceras subcrenatum was observed. This is now confirmed in the Geological Survey Ollerton Memoir (Edwards 1967). Twenty miles east of Sheffield at Ramskill, the G. subcrenatum marine band has been found, and in the Gainsborough area has been placed at an horizon containing deep water fauna of lingulae, spines and crinoid debris. North of the Humber there is no concrete evidence of the presence of the Gastrioceras zone.

On the northern flank, Owens and Burgess (1965) at Stainmore found G. cumbriense and a sandstone above, in turn overlain by a lingula band which they equated to G. subcrenatum. Taylor (1961) found a similar state of affairs at Whitehaven, though the sandstone was absent: the upper lingula band being equated with G. subcrenatum, the lower with G. cumbriense. Ford (1954) observed the G. cumbriense and G. listeri horizons in the Ingleton Coalfield, G. subcrenatum being possibly represented by a lingula brachiopod band lying upon the supposed Rough Rock. Wilson and Thompson (1965) correlated the whole of the northern flank with added localities in Colsterdale and Kirkby Malzeard, where the G. cumbriense marine band is goniatite bearing, and the G. subcrenatum/lingula bearing.

Accepting that over the Central Province, the position of the Rough Rock is the sandstone below the G. subcrenatum band and above the G. cumbriense Marine Band, we now have a state of affairs where different names exist for the same sandstone. This is mainly concentrated on the exposed west and north flanks of the province. In the centre, the complicating factor is the name of the flaggy beds below the usually massive Rough Rock, and the splitting of the Rough Rock into an Upper and a Lower Leaf by the Sandrock Mine, a thin coal with overlying shales and underlying seat-earth.

In N.E. Wales, Jones and Lloyd (1943) drew correlations between the Gwespyr Sandstone and Aqueduct Grit and the Rough Rock of the Pennine Area, though lithologically they did not resemble it; earlier, Wood (1936) also drew correlations, but neither worker adopted the name Rough Rock. In the vicinity of Oswestry, the Geological Survey place the Cefn y Fedw Sandstone in part at the Rough Rock horizon (Smith & George 1961), as does Williamson (1967, p.183), this is an exceedingly doubtful correlation caused by the absence of marker horizons. The presence of up to five separate sandstones between the marker horizons could be the cause of retaining the local terminology rather than adopting that used in the Central Pennines, where only two or three bands occur.

At Whitehaven the sandstone is absent, but over the rest of the northern flank the thick Laverton Sandstone at Stainmore and at Colstendale and Kirkby Malzeard, with underlying flags, is easily correlated with the Rough Rock succession in the Central Province area; again the local name is retained.

In the eastern area, the name Rough Rock has been adopted from the start, therefore no problem arises. In the Central Pennines the Rough Rock was termed Danebower Grit (Cope 1946a, 1958a) over the southern part of the Goyt Trough, though the term First Grit and/or Rough Rock is used to qualify it (Cope 1948a, 1958). This is in complete contrast to the other areas mentioned, as the Rough Rock had been in general use previous to Cope's new name. The term First Grit appears to have been dropped altogether, and the Geological Survey when remapping an area use Rough Rock as a replacement for earlier terms. Francis (1967) did not use Danebower Grit, and the Geological Survey (1969) did not use Coxbench Grit in the Belper area.

The same cannot be said of the flaggy sequence which generally occurs between the Gastrioceras cumbriense Marine Band and the base of the Rough Rock.

In the north, the flags first appear in the Colsterdale-Kirkby Malzeard area, where they are included in the name Laverton Sandstone, there being no shale between the two. In the Central Pennines and Rossendale areas the flags are separated from the Rough Rock by a variable thickness of shale. In Yorkshire they are termed the Rough Rock Flags, and in Lancashire, where they attain their thickest development, the Upper Haslingden Flags. Around Rochdale there are two flagstone bands, the upper being called the Hard Flags, and the lower, the Upper Haslingden Flags. This is an unfortunate reversal of nomenclature as in other areas the first flaggy sequence below the Rough Rock is termed Upper Haslingden Flags. In the western part of the Central Pennines, the Sandrock Mine, with associated seat-earth and mudstones, the mudstones in places containing freshwater lamellibranchs (Eagar 1952), splits the massive facies into an Upper and Lower Leaf, a feature absent in Yorkshire though shale bands and shale conglomerates may be present.

South of Oldham and Huddersfield, the underlying flaggy beds, if present, are not usually separated from the Rough Rock by shale. If a thin shale is present, it is rarely observed at outcrop, and for this reason the flags are included within the term Rough Rock (Cope 1948b, Myers 1952a,Eden et al. 1957).

To the east of Stoke-on-Trent and to the south of Sheffield, the flaggy lower sequence is absent. In the former area at Shaffalong and Cheadle the Rough Rock rests on red and purple shale. In the latter area, the normally massive Rough Rock has thinned to a flagstone sequence resting on shales, though it thickens to a massive sequence south of Ambergate.

Most of the local terms, except on the fringes of the Central Province, and in early Geological Survey literature which has not been brought up-to-date, are now obsolete, and the names 'Rough Rock' and 'Rough Rock Flags' have been generally adopted by the Geological Survey. The names at present in use still retain some of the most vague qualifying terms in geology: those of 'Rock', 'Flags' and 'Grit'.

The term 'rock' merely indicates an aggregate of mineral particles; it may be consolidated or unconsolidated, and either igneous, metamorphic or sedimentary - in fact, of any origin or composition.

The term 'flags' is a little more restricted, in that it implies a consolidated nature of either sedimentary or metamorphic origin. Both rock and flags mean little to a reader who knows little of the Namurian stratigraphy of Britain; in the East Midlands Oilfield, he might believe the Rough Rock to be a named tuffaceous horizon or a sandstone, as both occur in close proximity to one another. It is unfortunate that neither of these terms, which are now in general use, reveals the true physical character of the strata: they could be arenaceous, argillaceous or calcareous, if one is dealing with a sedimentary feature.

The term 'grit' is a little less vague in that it implies a sedimentary origin of an arenaceous or calcareous material. The term has generally been confined to sandstones with angular grains of a size between ½ mm. and 1 mm; sandstones with smaller or larger angular grains have the qualification, 'fine grit' or 'coarse grit' (V. Allen, 1936). Strata termed 'grit' in the British stratigraphical column range from Palaeozoic greywackes - Aberystwyth Grits, to Jurassic Calcarenites - Trigonia Grit. Morton in 1712 even referred to oolites as 'spherical grit', (Challinor 1962). R.K. Harrison, in the Geological Survey Chesterfield Memoir (Smith et al. 1967) recognised that the term 'grit' as applied to the Millstone Grit sandstones was petrographically a misnomer, since gravel- and coarse sand grade components were commonly rounded to sub-rounded.

The sandstone making up the Rough Rock may be coarse, medium or fine, and either flaggy or massive. At Danebower, the type locality of the Danebower Grit, it is dominantly flaggy, a feature shown by the name 'Dane Slate Quarries'; in the upper reaches of the Goyt, fine-grained beds with calcite cement occur. The most suitable name, therefore, appears to be Rough Sandstone, with any qualifications included in brackets, e.g. Rough Sandstone (flaggy). It implies only that the deposit is arenaceous, a feature which must be borne in mind when naming such a variable sandstone. The author sees no reason to change the term 'Rough', as it has no regional derivation and has now been in use for over a century. Some may argue that it implies a coarse sandstone; in part, they are correct (cf. Roughcast), but any alteration would be against the general trend of adopting the name Rough Rock nationally, for the sandstone between Gastrioceras subcrenatum and Gastrioceras cumbriense. The use of fossil names, e.g. Subcrenatum Grit for the Rough Rock, has been attempted before, but was not accepted; e.g. Cancellatum Grit (Slinger 1936) was superceded by Meanwood Sandstone, being the sandstone immediately below the G. cancellatum Marine Band.

Chapter 3

Sedimentological Studies on the Rough Rock

Very few contributions have been made to the study of this uppermost Namurian sandstone, even though it has been used as a junction sandstone of the Namurian-Westphalian for over forty years, economically used as a source of building stone, glass, placer and foundry sand, and was one of the gritstones studied by Sorby (1859).

From studies of false, drift and current bedding, which he had shown to be reliable indications of current direction, he concluded that the Millstone Grit of south Yorkshire was derived from a north-easterly direction. He realised that mineralogical examination of the sandstones and their included pebbles could supply information as to the nature of the source region. To this end, the pebbles would yield the most direct evidence.

Thin sectioning allowed him to identify, in addition to quartz pebbles of various types, pebbles of feldspar, quartz-schist, mica-schist, syenite and "....pebbles of undoubted granite".

He thus concluded that, "....the materials composing the Millstone Grit in south Yorkshire were, to a great extent, derived from the waste of land consisting of the so-called Primary rocks." The area of derivation he gave as a land mass located somewhere in the area occupied by the North Sea.

Over sixty years elapsed, from 1859 to 1919, before any further substantial contributions to Millstone Grit sedimentology were made. Between these dates, only cursory data became available, mainly through the early work of the Geological Survey (Gibson 1905, etc.) and a borehole log from Meanwood, Leeds (Gilligan 1915). These were limited to brief descriptions of the sandstones, viz. coarse grit with abundant feldspar; fine grit; grit with pebbles; - though Hull & Green (1866) gave a more detailed section of the Rough Rock encountered on Congleton Edge, Cheshire:-

	ft.	ins.
Rough Rock, coarse massive grit and conglomerate		
White sandy clay, with a bed of sandstone at the bottom	3	0
Pink and white sandy clay, with beds of sandstone	13	0
Hard fine grit, in parts a conglomerate	10	0
Pink and white sandy shale, with beds of sandstone	14	0
Hard fine sandstone	5	0
Shale, sandy and pink in the upper part, dark and clay lower down	57	0

Such a detailed section is uncommon in the early literature. Petrographic information from Geological Survey work was almost non-existent; mention of the presence or absence of feldspar, mica and pebbles was the most one could hope for - a state of affairs which existed until 1968 (see p.30). Pickering in 1911 examined the Rough Rock at Crag Hill, Horsforth. He found grains ranging from 1·5 inches to 0·1 inches, the pebbles mainly being derived from a metamorphic parent rock, though felspar, granitic, pegmatitic and sedimentary rock pebbles were also observed. He also observed but gave no reason for shale pebbles. Of 16 cross-strata measured, 9 were to the south-west.

"The petrography of the Millstone Grit of Yorkshire" (1919), by A. Gilligan, was a consequence of Sorby's work, and followed his methods of observation. Gilligan's study was fairly exhaustive and combined petrography and palaeogeography. He recognised pebbles of quartz, microcline, pegmatite, granite, quartz and feldspar porphyries, granite-gneiss, mica- and quartz-schist within the Millstone Grits. The Rough Rock is periodically mentioned throughout the paper. Gilligan noted the common occurrence of a blue or opalescent quartz, the angularity of quartz grains, and abundance of garnet and monazite in heavy mineral-rich layers found in the Rough Rock at Horsforth, near Leeds; the presence of calcite cemented sandstone, and pebbles of sedimentary origin with included organisms. He was the first person to observe, and give an explanation for, shale conglomerates and small shale partings in the Millstone Grits.

> "Do they represent small mud-puddles infilled at the time of the accumulation of the surrounding coarse material, or are they true pebbles derived from a consolidated shale? The small masses, 1 inch or less in diameter, lie in all directions in the grit; they seem to be transported, and may possibly represent fragments of clay slate." (Gilligan 1919, p.259)

His conclusion on the palaeogeography agreed with that of Sorby. St. George's Land as a source area was discounted owing to its probable size and lithological character. The rock types present as pebbles in the Millstone Grit contrasted with possible parent rocks in Ireland, the Lake District and the immediate Scottish Highlands. The main source area lay to the north and east of Scotland with an extension of Scandinavia, the latter being of considerable relief, subject to tectonic activity, and climatically of monsoonal type. This conclusion on source area was partly based on the resemblance of some pebble types to the rhombporphyry of the Christiania (Oslo) region; this porphyry has now been dated as Permian, and thus the conclusion needs modification.

In 1929, Wray, in "The Carboniferous Succession in the Central Pennine Area", described the Rough Rock as the most constant and uniform of all the Millstone Grits, of a uniform coarse-grained and massive nature. He gave its thickness over the area as 100'-120', with an included coal seam, the Sandrock or Feather Edge coal, in Lancashire. Wray & Melmore (1931) reiterated these statements. Pulfrey (1934) merely mentioned the Rough Rock as being poorly developed at Rod Moor, Sheffield, and in the included borehole log he gave its thickness as 36 ft., composed of massive, coarse current-bedded sandstone. Hudson & Dunnington (1940) gave the Rough Rock, at Bradford, a thickness of 80 ft., composed of coarse, false-bedded sandstone passing upwards into micaceous flagstones. In 1940, at Fairweather Green, Bradford, they described the Rough Rock as "....coarse-grained massive false-bedded grit with large rounded quartz pebbles, approaching one inch in diameter, and a large proportion of feldspar" (Hudson and Dunnington 1940, p.219).

North-east Wales was extensively investigated in 1936 by Wood, and in 1943 by Jones & Lloyd. They both equated the Gwespyr Sandstone and Aqueduct Grit with the Rough Rock and Haslingden Flags. They gave the lithology of the Gwespyr Sandstone as medium to fine grained with shaly beds and plant impressions, and with only small amounts of feldspar; on the other hand, the Aqueduct Grit contains much partly decomposed feldspar, a feature, according to Wood, of a drier climate or more energetic denudation.

Cope, in 1948b, produced the detailed log of the Alders Farm Borehole, which showed the Rough Rock to consist of white to purple current-bedded grit with included micaceous layers, conglomerate bands and shale-pellet bands. Myers (1952a)gave the log of the Stockton Brook Borehole, 5 miles south of the Alders Farm Borehole, though this contained few details, mainly giving colour and grain size of the Rough Rock.

Eden (195), writing on the East Midlands Coalfields, equated the Rough Rock with the Coxbench and Longshaw Grit, describing the Rough Rock as a coarse feldspathic sandstone or fine grit, with a maximum thickness of 100 ft. at Coxbench Quarry, diminishing to 52 ft. in the Cotgrave Bridge Bore, and 68 ft. at Bulgate, though in neither case was the full thickness proved. Stephens (1953), studying the 'Rough Rock' near Crich, divided it into two leaves, and observed the upper leaf to feather out. Current data from the upper leaf had a northerly trend. It has now been found that this upper leaf is, in fact, the Crawshaw Sandstone.

In 1953, Broadhurst was the first to observe contorted sandstones in the Millstone Grit; an example near Aspenshaw Hall, north of Hayfield, belonged to the Rough Rock, and was attributed to subaqueous sliding or slumping, accepting the recent Geological Survey interpretation north of Hayfield, the example at Aspenshaw Hall belongs to the Woodhead Hill Rock, thus Broadhurst's second locality at Matleymoor Farm is now placed in the Rough Rock. Greensmith (1957), working on the Smeekley Wood Borehole, south of Sheffield, described the thin band of Rough Rock as a quartzite, the dominant cement being quartz, with subsidiary calcite, dolomite, chalcedony and kaolinite. He observed that there was no interpenetration of the original cores of the quartz grains, and both the feldspars and quartz showed corrosion wherever they were in contact with calcite. The composition of the Rough Rock was 2½% feldspar, 3% clay and 94½% quartz.

The most areally extensive study of the Rough Rock was undertaken by J.S. Shackleton in 1962. Tracing the Rough Rock horizon throughout the Central Province, he found a regionally consistent pattern of current-bedding direction to be present, indicating sediment movement from north-east to south-west. Marked divergence from this pattern occurred only south of Macclesfield and Sheffield, where current-flow was seen to be from east and west. He also analysed the thickness of the cross-sets and the change in direction of the cross-strata against their vertical position within the Rough Rock, noticing that the direction changed from south to south-west during Rough Rock times. The cross-strata were observed to be mainly of a tabular nature. Few other structures were discussed at length. He found the average feldspar content to be 20%, and termed the Rough Rock an arkose. In shape, the quartz grains below 2 mm. in diameter were sub-rounded to sub-angular, while above 2 mm. they were usually well rounded. Microcline was fresh in thin section, whereas plagioclase was much altered. Shackleton considered the Rough Rock to be a fluvial fan deposit, transported by a host of relatively small rivers, aided by torrential rainstorms and flash floods. He compared the Rough Rock with the Benen Sandstone of the Appalachian Basin and the Lafayette Gravel of the Tennessee River. Unfortunately, south of Sheffield and Stockport, he took data from other sandstones, owing to the use of out-of-date Geological Survey maps: only in the Stoke-on-Trent area did he extract data from the true Rough Rock (see fig.4).

M.D. Wright (1964a) dealt with the compaction of the Rough Rock, counting the number of grain contacts per grain. A specimen of Rough Rock from the Roches of Staffordshire was porous and revealed grain-contact averages of about four, compared to higher values in sandstones from other areas. He attributed this to the lesser thickness of the one-time overlying rocks in this area. Wright (1964b), dealing with cross-bedding in the Millstone Grit, gave an example from the Rough Rock of Cracken Edge (Derbyshire), attributable to trains of longcrested mega-ripples. Wright's (1964c) partial study of the Rough Rock gave examples of sudden thinning, the sandstone occurring as steps cut into the underlying shales, at Cracken Edge and in the Lancashire Coalfield. At Cracken Edge he also gave examples of the trace-fossils included in the Rough Rock. Reading (1964) briefly mentions the Rough Rock in his paper, "A review of the factors affecting the sedimentation of the Millstone Grit (Namurian) in the Central Pennines", though he only quotes Stephens' and Shackleton's work, misquoting the latter, and giving the thickness of the Rough Rock as 200 ft. instead of 70 ft., the Rough Rock Group being 200 ft. thick.

In 1967, the Geological Survey first introduced a section on the petrography of the sandstones, though the Rough Rock, being only poorly developed and exposed, was not sampled (Harrison in Smith et al., 1967). The publication of the Macclesfield Memoir in 1968 saw the first detailed petrographical analysis to include the Rough Rock. The average mineral composition of the seven samples analysed was: 84% quartz, chert, rock particles and muscovite, and 12% feldspars, kaolinite, biotite, chlorite and rock particles. In the heavy mineral count, zircon accounted for 75%, tourmaline, rutile and leucoxene accounted for 12%, and traces of anatase, ilmenite and monazite were found; garnet, apatite and spinel were absent. Parts of the Rough Rock were classed as immature sandstones, noticeably coarse-grained, less well-packed, and containing conspicuous feldspars and kaolinite. In places, the Rough Rock was poorly consolidated: this was thought to be due to defeldspathisation (Harrison in Evans et al. 1968).

The most recent works involving the Rough Rock are: the very brief account of Morris (1969) on the area north-east of Cheadle, Staffordshire, and P.H. Sabine's (1969) publication on the geochemistry of sedimentary rocks. The former shows the Rough Rock to have a uniform grain-size of about 1 mm., with coarser and finer bands; cross-bedding and quartz pebble bands also being present. The latter publication gives scanty geochemical data on 3 samples from Mow Cop, Hurst Quarry (Biddulph) and Foxt, with detailed geochemical petrographical data on 2 samples from Mow Cop and Belper.

Conclusions

The main short-comings of research on the Rough Rock have been:-

1) Data extracted from a sandstone other than the Rough Rock.
   eg. Shackleton (1962), Stephens (1953), Wright (1964a), Broadhurst (1953).

2) Data obtained from a restricted area or from one locality.
   eg. Stephens (1953), most of the work before 1920, Morris (1969), Greensmith (1957).

3) Data taken from a large area but not on a close network.
   eg. Shackleton (1962), Gilligan (1919).

4) Location from which data taken not given in detail.
   Many papers.

5). Environmental significance given to data obtained from a restricted area, with little consideration of the Rough Rock within the region.
   eg. Wright (1964b), Stephens (1953).

6) Conclusion for the whole area based on restricted observation and information.

   eg. Reading (1964).

7) Subjective reasoning.

   eg. Stephens (1953).

8) Unrepresentative.

   eg. Morris (1969).

Chapter 4

Aims and Techniques

Aims

The primary aim of this investigation is to locate any effect due to contemporaneous movements and/or differential subsidence of the sub-surface Lower Carboniferous and Basement and along the major structural trend lines (Malvern, Church Stretton and Charnwood), upon the sedimentation and palaeoenvironment within the Rough Rock. Howitt and Brunstrom (1966) recognised that the influence of the Blocks and Gulfs was traceable into the Lower and Middle Coal Measures, in the East Midlands, although the effect at this level was relatively minor. It seems likely that at the level of the Rough Rock these movements should be observable without too much difficulty, though the pin-pointing of any one cause would be difficult owing to the depth of the cover. The variation in facies and thickness between the Blocks and Gulfs would cause differential subsidence, and the boundary zones, possibly due to deep seated faults, would, if movement was present, cause changes in sedimentation, as would any movement along other major structural lines.

To attain this goal it was proposed to study the facies of the sandstone and map their areal and vertical variation as well as to extract directional data from the sandstone which together with the analysis of certain internal structures would create a regional pattern capable of being analysed, using known sub-surface and outcrop data from lower down in the Carboniferous succession, together with known structural and palaeogeomorphological trends. Bluck (1961) had successfully used these methods to demonstrate the presence of a basin during Lower Coal Measure times in the South Wales Coalfield.

Having attained this type of analysis for the area to be covered, it was proposed to incorporate information, especially palaeo-current, from the surrounding area and form a large-scale picture of conditions in the Rough Rock for Northern England which would be a stimulus to any further research on sandstones at the boundary between the Namurian and the Westphalian.

The area as laid down in Chapter 1 was finally chosen because it contains within its boundary, the so-called Derbyshire Dome and its bordering reef belts, the Gulfs of Edale, North Staffordshire and Widmerpool, together with the known shelf area of the East Midlands, and is the focal point of the three major tectonic trend lines.

Within the area, the study of the Rough Rock and Immediate sandstones had been almost completely neglected, due to the primary necessity to locate faunal horizons, in favour of the area to the north, which itself had only been scantily covered. From research carried out in the northern half of the outcrop, numerous problems came to light which could be furthered in the area covered here; of these, the search for examples of contorted strata and their probable genesis together with the attempt to trace the Sandrock Mine horizon of Lancashire southwards into the area are of paramount importance.

Techniques

Field

The main weakness in previous research has been the failure to locate satisfactorily the Rough Rock over the whole area dealt with. For this reason the field was divided into three sections. Areas which still remain in doubt are marked on the map. (Enclosures 2 to 5)

The first stage was the search for the confining marine bands, Gastrioceras cancellatum, G. cumbriense and G. subcrenatum, from both sub-surface and outcrop. If only the G. cancellatum band was observed, or none of the bands could be located, within an area, the horizon was interpreted from bordering areas; failing this the area was classed as doubtful. The areas around Belmont Hall, north-west of Cheadle, Mow Cop, and Eddisbury Hill, near Macclesfield, can be classed as doubtful (Fig.5).

The second stage was the actual extraction of data from the confirmed Rough Rock, the basis of which was the measured section and the outcrop traverse.

Section measuring was carried out in scarp slope streams, which in many cases exposed the greatest vertical thickness over the least horizontal distance, and in quarries, where the vertical walls gave a good but frequently inaccessible section.

Measurement of sections was usually by tape, to the nearest ½", though in some streams where gaps occurred, or the gradient was low,a

6' ranging pole with a crude eyepiece and levelling device incorporated on the top was used, in preference to an Abney Level. In quarries and scarp exposures where the full height of the face was inaccessible the range was placed in a vertical position as high up the face as possible and a single or composite photograph taken, thicknesses were then calculated from an enlarged print using the 1' scale of the ranging pole; this proved to be accurate to the nearest inch. On a slope the same principle was used provided a marker band was visible.

Finally, the third stage was the collection of bulk samples and taking of specialised photographs. By using this three-fold system the area was well covered and the outcrop could be walked systematically and without bias, also preventing the study of two completely divorced areas and allowing three miles of outcrop to be under study at any one time.

Mapping

Mapping was based on the checking of previous outcrop mapping by F.W. Cope and the Institute of Geological Sciences, on the 6" to 1 mile scale and filling in the details of the sandstone between the mapped boundaries. This was then transposed on to 2½" to the mile maps for reproduction.

Data Collection

Grain size was judged using a portable scale of grains of different sizes, corresponding to the Wentworth scale.

Directional structures were measured with a 'Silva' compass/ clinometer to the nearest 1° in each case. Data taken from linear structures, such as grooves, primary current lineation and plant fragments, were recorded without any suggestion of the sense of movement. Ripples were measured only in plan view when their crests or 'Rib and Furrow' were visible. Similarly, trough cross-bedding directions were measured only in plan view, the directions of the axes being estimated by eye rather than by plotting out the poles of foresets around the troughs. In the case of tabular sets with planar cross-bedding, measurement was taken directly from the plane of the foreset and held to be representative of the set.

No more than one measurement was taken from each set, and a rough statistical sampling system involving 440 yard traverses was used in open country.

Data collected were entered in two types of field note-book. The number and location of all localities, together with data and descriptions of small outcrops, in a lined note-book. Sections were entered in a surveyor's note-book.

Laboratory Methods

The measured sections were re-examined, and each bed allocated to a facies and coloured according to a code; only in the case of data from boreholes where examination was not possible was this system not used. Borehole data obtained from the Geological Laboratories, British Industrial Sands, Redhill, was coloured according to the colour of the rock met with in the borehole core, as in the majority of the boreholes the facies met were similar. The sections and information from open country mapping were combined to produce facies maps for sub-areas 1, 2, 3 and 4. (Enclosures 2, 3, 4 & 5 respectively)

Palaeocurrent data were corrected for secondary tilt and transferred to rose-diagrams, as the spread of readings was usually below 90° and grouped, the arithmetic, rather than the vector mean, was calculated. The data for a sub-area were then calculated and placed on a rose-diagram.

Petrographic Methods

All specimens collected in the field from all facies were examined in the laboratory. Most specimens were examined in thin section, all specimens were examined from a cut and varnished surface. The latter were used for the examination of smaller sedimentary structures. Only pebbles were collected from certain localities and sorted into different types. Two types of measurement were made on thin sections:-

(Point-Counting). Thin sections were point-counted for quartz, feldspar, mica, carbon, and matrix. Counting was done using either a microscope or a 'Shadomaster' depending on the number of categories present. Checks were made when using the latter by comparing results from the same slide under the microscope. The 'rock fragment' category was recognised only for shale pebbles; this was so because of the difficulty of distinguishing original polycrystalline grains from diagenetically associated single grains. Material which could not be resolved was assigned to the matrix class. It included primary and diagenetic clay minerals, and clay minerals due to the recent weathering of feldspars. If any clay mineral was seen to partially replace or pseudomorph feldspar, it was counted as feldspar. The feldspar group was not split into groups.

(Grain-size Analysis). On account of diagenetic effects the disaggregation of many specimens for analysis was impossible. Most grain-size measurements were, therefore, carried out on thin sections. They were projected on a 'Shadomaster' at a known magnification and the lengths of the longest grain dimension measured directly using a scale inscribed on a transparent film. A 1 cm. sample grid was used, and a measurement made at every grid point even when a grain fell on more than one point. The measured grains were allocated to Ø classes and plotted as cumulative curves.

Data collected from B.I.S. Redhill are given as the percentage held on 72 mesh and 270 mesh.

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Section 2

THE DATA

Chapter 5

Lithofacies

Introduction

The term 'lithofacies' is used here in a descriptive sense, for a group of rocks differing from others by virtue of their field aspect. This is controlled by parameters such as grain size, composition, geometry of the body, size and types of sedimentary structures, and occurrence of, or any contemporaneous action of, organisms within the sediment.

Most lithofacies could be subdivided by using minor details as limiting factors. The approach, here, however, is to define as few lithofacies as possible, though having enough to show the range of processes which operated. This would allow any future investigator to commit most of the divisions to memory, thus making them useful in the field. The separation and limiting values of facies is subjective, as most are intergradational. The recognition of any lithofacies does not completely rest with any one parameter, eg. grain size; on the contrary, different facies quite often have different guiding parameters, though a proliferation of facies names was avoided if a parameter occurred in most facies types by dealing with it under a separate heading.

The parameters making up a facies may indicate only the processes that operated on a sediment during and after its deposition, and may have little absolute environmental significance. Therefore, each lithofacies will be described, and the operative processes inferred, and in a later chapter the lithofacies will be put into associations as a prelude to understanding the palaeogeography of the area.

The distribution of major lithofacies types are shown on Enclosures 2 to 5.

As this thesis is mainly concerned with the sedimentology and palaeogeography of the Rough Rock, the first three lithofacies fall slightly outside the realm of this study. They have, however, been included to offer direct assistance in the elucidation of the problem.

LITHOFACIES 1 - Mudstone with marine fossils.

Description:

This lithofacies is confined to three distinctive stratigraphic horizons, the *Gastrioceras cancellatum*, the *G. cumbriense*, and *G. subcrenatum* marine bands. It consists of very fine-grained, grey or blue/black, slightly micaceous mudstone. The bedding planes are often sulphurous, and it appears that decalcification has occurred at some time. When fresh, the mudstone is massive or blocky, but on weathering it becomes highly fissile, due to the high organic content, splitting into paper-thin, parallel bounded sheets. Petrographically, the mudstone is largely made up of clay minerals, and carbonaceous material; 99% of the material being less than 50 microns in diameter, and clay minerals forming 70% of the whole. The remaining 1% is made up of quartz and mica, ranging up to 500 microns in diameter (Heptonstall, 1964, Broadhurst and Loring, 1970, Haslam, 1966).

The three marine bands show faunal phases, from Dunbarella near the base and top, to Gastrioceras in the middle, the smallest individuals being in the very middle. This phasing is also present in sediment colour and lithology, becoming darker and higher in organic content towards the middle. All three marine bands are split by light grey, barren mudstone, with the darkest mudstone of the band being immediately above and below.

The marine bands vary in thickness over the area; the G. subcrenatum band from 15 cm. in the upper Goyt, 40 cm. at Shaffalong and Ambergate, 55 cm. near Sheffield, to 80 cm. in the Ridgeway Borehole (N.G. SJ 8903 5375) near Norton-in-the-Moors. The G. cumbriense marine band is usually less than 15 cm. thick over the whole area; the G. cancellatum marine band has a fairly constant thickness of 75 cm. to 85 cm.

The fossils are usually found in a flattened state on the planes of lamination, though in some zones of the marine band there occur many venter impressions denoting preservation while in a vertical or near-vertical position. At Wall Grange (N.G. SJ 9635 5324), (Plate 5), solid forms of G. cancellatum were found in bullions (Cope, pers. com.). Apart from the Gastrioceras, Lingula, Dunbarella, Orbiculoidea, Posidonia, Anthrocaceras and Orthoceras species, and plant fragments found in all the marine bands, Reticuloceras is found in the G. cancellatum marine band and Homoceratoides in the G. cumbriense marine band.

Heptonstall (1964) working on the G. cancellatum marine band, used the plant fragments and goniatites preserved as venters as indicators of current directions with remarkable success, observing a preferred orientation showing the palaeocurrents in the Pennine area to have flowed from a northerly/north-westerly direction, the only exception being at Orchard Farm (NG. SK 0222 6900), where the variance was high, and at Stalybridge, where there was recognisable variance. Haslam (1966) also noted similar preferred orientations from fossil material in the G. cumbriense marine band of Disley and Bollington (Cheshire).

Interpretation

The fine grain size, parallel lamination, and high organic content suggest that the mudstone was deposited in quiet conditions, by accumulation from suspension of fine-grained material. Because the toxicity is greatest in the middle of the band, as shown by the high organic content and decreasing goniatite size, it is also reasonable to assume that sedimentation was at its lowest, and that the marine incursion was at its peak. Pauses possibly did occur allowing the deposition of a barren grey mudstone, though the absence of fossils may be due to increased sedimentation. No depth connotation can be placed on the lithofacies, but from the palaeocurrent evidence it must be assumed that currents were present, though probably very gentle; the force required to orientate a goniatite near to neutral buoyancy and to move small plant fragments is negligible.

LITHOFACIES 2 - Mudstones and Siltstones.

Description

This lithofacies is gradational with lithofacies 1, Mudstone with Marine Fossils; 3, Ganister Seat-earth and Coal; 7, Mudstone Pellet Conglomerate; 9, Medium-scale Cross-bedded Sandstone; and 11, Ripple-bedded Sandstone. It consists of mudstones and siltstones, lacking sand-sized particles, except for carbonaceous fragments and mica flakes.

This lithofacies consists of fine, non- or poorly-laminated black, blue/black mudstone, to laminated grey/green, grey to pink laminated mudstone, and siltstones, in places sulphurous and distinguished from Lithofacies 1 by the absence of marine fossils.

There are all gradations between the extremes of mudstone and very coarse siltstone; fine ironstone bands and nodules occurring at sporadic intervals, whilst nearest to the base of the Rough Rock, in some localities, interlaminations of carbonaceous mudstones and siltstones occur.

The general appearance is a blocky striped mudstone with parallel bedding and laminations, with occasional thin, 5 cm. bands of sideritic/ limonitic very coarse siltstones, coarsening upwards. The lamination is largely due to the horizontal orientation of mica flakes and carbonaceous fragments.

Current-orientated features are generally absent, and trace fossils are generally few in number. Sporadic occurrences of plant debris are observed at a few horizons. The thickness of the mudstones and siltstones between the G. cumbriense marine band and the base of the Rough Rock varies between 50 m. and 100 m. (Plate 5).

Mudstone partings and bands occur within the Rough Rock at Mow Cop Quarry (N.G. SJ 8681 5850) (Plate 6), Moneystone (N.G. SK 0500 4650), Foxt (N.G. SK 0360 4855), and in the Goyts Moss area. In general, the mudstone bands rarely exceed 30 cm. thick, and are usually pink to grey in colour. At Mow Cop Quarry, eight bands of white/green kaolinitic mudstone occur in the lower part of the Rough Rock; no laminations are visible, though occasional red staining is observed, which shows up an otherwise poor lamination within the mudstone. The overlying sandstone is heavily load-casted into the mudstone, the load-casts having a rough orientation. Similar banding is observed at the Cat and Fiddle Quarry (N.G. SJ 9990 7240).

A special and localised feature deserving particular mention is the mudstone containin non-marine pelecypods and plant fragment concentrations. It occurs at three separate horizons within the Rough Rock Group, of the Central Pennines; approximately 6 m. below the base of the Rough Rock, at the Sandrock Mine horizon within the Rough Rock, and between the top of the Rough Rock and the Gastrioceras subcrenatum marine band. Only the Sandrock Mine horizon occurrence affects the work of this thesis, the other two being absent over the area concerned here, though present just to the north of the northern boundary.

This consists of green/grey to blue/black, slightly micaceous mudstone containing the non-marine pelecypods, Carbonicola sp., and Anthraconaia sp., together with abundant plant fragments, which occur up to 120 cm. above and below the 30 cm.-thick pelecypod horizon. In the area concerned here, the latter has not been seen in situ by the author, due to peat-slip, though the plant-rich mudstones are observed in the shale intercalations south of the Cat and Fiddle Inn (N.G. SJ 997 716), and in the vicinity of Errwood Hall (N.G. SK 0110 7495). Cope (pers. com.) has observed the pelecypod horizon at the Cat and Fiddle locality.

Interpretation

The absence of features specifically indicative of current activity, together with the fine-grained nature of the sediment suggests that this lithofacies was deposited in quiet, fairly restricted water, by material falling from suspension, though with the possibility of a very low flow regime operative at certain times; sediment being moved on a plane bed without the formation of structures. This could be the case in the siltstones just below the base of the Rough Rock, where carbonaceous laminations between the siltstones bands are unbroken, except for the small amount of furrowing which has taken place.

At other times, sedimentation from suspension may have fallen below the usual rates. The concentration of non-marine pelecypods is high in blue/black carbon-rich mudstone, and low only in the grey/green mudstone. Eagar (1951, 1953) believes that shell-size and population density are related to the rate of sedimentation, courseness of sediment (turbidity), salinity, and organic content.

No obvious environmental significance can be attached to this lithofacies, which could have been deposited in a wide variety of environments, the most plausible being the estuarine, lower flood plain, overbank or fresh-water lake environments.

LITHOFACIES 3 - Seat-earths, Ganisters, Ganisteroid Sandstones and Coal.

Description

These four separate lithofacies are described together because of their close association and small volumetric importance (Plate 7).

Seat-earths are recognised by the presence of rootlets apparently in the growth position. The sediment in which they occur varies from a soft grey to pale green/blue clay to pink fine-grained siltstones, and ripple-laminated silty sandstone, with limonitic patches. They tend to have a basal coarse layer of fine sandstone, with a low concentration of rootlets, passing up rapidly into a true silt or clay, with abundant carbonaceous material. The seat-earths are well developed in the Potteries area, where they attain a thickness of up to 2 m. (top of the Rough Rock at Coal Pit Ford near Shaffalong (N.G. SJ 9542 5158)), though the average thickness is only 80 cm. to 90 cm. At Consall (N.G. SJ 9795 4802), the seat-earth has diminished to only 20 cm. with ganister bands above and below, the colour ranges from pink to grey. In the Sheffield area, the seat-earths reach their thickest development, represented by 170 cm. of grey to pale green clay (the Pot Clay horizon), though in places, ganister is associated with it. In the Goyt Trough area, and south of Holymoorside, ganisters/ ganisteroid sandstones become more common, being in places the only rootlet bed existing, especially between Holymoorside and Ambergate. The ganister and ganisteroid sandstones are grey/green to blue in colour, containing abundant rootlets and leaf impressions. The true ganister is confined to a few thin bands in the Goyt Trough and Alton Quarry section (N.G. SK 3620 6450), being well cemented with silica. The most common type is the ganisteroid sandstone, which is less well cemented but with the same organic content and colour. The ganister may attain one metre (Alton Quarries), but in most cases ranges from 30 cm. - 60 cm. The ganisteroid sandstones, on the other hand, have a large variation in thickness. In the Goyt Trough area, the true ganisters rarely exceed 22 cm. whereas the ganisteroid sandstone have thickness in excess of 1 m. (Stake Clough (N.G. SK 0075 7310)).

Coal is poorly developed at this horizon over the whole area, and is with only one exception representative of the Six Inch Mine of Lancashire, and the Pot Clay Coal of Yorkshire, attaining a maximum of 18 cm. in the Upper Goyt region. In the Potteries area, only a 2 cm. - 3 cm. band of sooty coal is recorded at Mow Lane Quarry (N.G. SJ 8730 5915) and Consall; it is not recognised in the Alders Farm (N.G. SJ 8960 6208), and Ridgeway Boreholes, and is absent in the Oakamoor Borehole (N.G. SK 0498 4559).

In the roadside quarry west of Danebower (N.G. SK 0100 7000), a sooty, 1 cm. band of coal is observed above a laminated pink fireclay, above the coal there being a mudstone pellet conglomerate, and a coarse sandstone full of large wood fragments. This is possibly the only representative of the Sandrock Mine within the area (Plate 8).

In the Sheffield to Derby area, the coal is thin: 10 cm. at Stonehay (N.G. SK 3319 6749), 8 cm. at Harewood Grange (N.G. SK 3120 6840), and 4 cm. at Hall Broom Quarry (N.G. SK 2760 8375).

Interpretation

The presence of rootlets indicates that vegetation was growing in the area and that the overlying coal was probably autochthonous. The fining upwards, together with the sudden decrease in grain size and the upward increase in carbonaceous fragments suggests that the siltstones were being deposited after the onset of plant colonisation, but that the colonisation had a marked effect on the competence of the currents, and that this effect was fairly sudden and probably depended on a critical limit of colonisation.

The presence of ganisters and ganisteroid sandstones also indicates that vegetation was growing, but that the influence of the currents was not affected to such an extent as were the currents during the deposition of the seat-earth. Williamson (1967) believes the ganisters represent increased emergence; this may be coupled with the possibility of less colonisation, therefore allowing better water movement.

The poor quality, sparcity and thinness of the coals suggest that a good establishment of growing peat in the area rarely occurred, and when it did, it was only sporadic and local.

The environment of deposition of this lithofacies must have been in very shallow water, with, on occasions, slight emergence as might be found in present-day lagoons, delta top interdistributory areas, shallow lakes, coastal plains and fluvial overbank areas.

LITHOFACIES 4 - Shale-pellet Conglomerates

Description

This facies is confined to a few distinctive bands varying between 5 cm. and 20 cm. thick. It is gradational with all other lithofacies except lithofacies 1, Mudstone with Marine Fossils, and 3, Seat-earth, Ganister, etc. It consists of shale fragments between 3 mm. and 20 mm. long in a matrix of sand-sized particles, occurring in all areas, though except in the Goyt Trough it is confined to the lower 2 metres of the Rough Rock and the Rough Rock Flags.

In the Rough Rock Flags it is observed at Billinge Hill (N.G. SJ 9548 7775) and Big Low (N.G. SJ 9570 7705) near Rainow, east of Bollington, consisting of dark grey contorted mudstone fragments from 5 mm. to 20 mm. long set in a clean coarse, medium grained sandstone. The coarse quartz sandstone in which they occur shows evidence of erosion into a thixotropic laminated clean sandy siltstone, the included mudstone fragments having smooth external surfaces with only occasional pitting by sand-sized particles, though the mudstone fragment as a whole may be twisted almost to a point of rupture. At first glance the structures appear as large pelecypod burrows; this, though, is ruled out, as the disturbance of the laminated layers occurs beyond the sharp boundary of the coarse sandstone.

In the base of the Rough Rock this facies occupies a thickness of from 15 cm. to 30 cm., though a decrease in the abundance of shale fragments in the thicker units is observed in the upper 15 cm. of the layer, there being only 5-10 fragments per square metre in the upper 5 cm. The included mudstone fragments are green/grey, in general non-laminated, though weak laminations were observed in four fragments from The Scours (N.G. SJ 9907 7145), west of the Cat and Fiddle Inn. As before, the grain indentation amounts to at the most only half a grain in diameter. The enclosing sand has only a slightly lighter colour around the borders of the fragments, for a thickness of 1 mm. - 2 mm. The mudstone fragments range from 8 mm. to 18 mm. along their longest axis and are only occasionally flattened; they are rarely contorted. Shale pellets of this kind are observed at Whiston Hall (N.G. SK 0425 4720), Coalpit Ford Farm, in the Trent Valley (N.G. SJ 9007 3538), The Scours, Danebower Hollow (N.G. SJ 9990 7050), Errwood Hall, Cracken Edge (N.G. SK 0370 8360), and near Moorfield Farm, west of Sheffield (N.G. SK 2850 8423).

The most important section of this lithofacies is the intraformational mudstone pellet conglomerates occurring on the south-westerly and southerly edges of the Goyt Trough between Black Clough

(N.G. SK 0120 7680), and Stake Clough (N.G. SK 0100 7350), the central and northern part of Cracken Edge Quarries, and at Mow Cop Quarry and Alders Farm Borehole, Timbersbrook, in the northern part of the Potteries Coalfield. The mudstone pellets range in colour from grey/ green to pink in the Goyt Trough, to a chocolate red in the Mow Cop Quarry and Alders Farm Borehole, to pale green in the upper layers of the Rough Rock in Mow Cop Quarry (Plate 9).

In the southern Goyt sections, the pellet horizons attain a maximum thickness and frequency at Stake Clough, where there are four horizons, each overlying a band of laminated pink to buff silty mudstone and occurring in a section 5 m. thick. The bands vary between 3 mm. and 8 mm. in thickness, the frequency of pellets decreasing upwards. To the immediate north of this locality, pellets are not observed; to the south the frequency of pellet horizons decreases to three at Danebower Hollow and The Scours, one of these horizons being above a mudstone band, with abundant plant fragments in both cases, and to two horizons in the roadside quarry west of Danebower Quarries. In the latter locality, the pellet horizons are 4 cm. thick, the upper horizon lying above a grey mudstone, while above it rests a sooty horizon 5 mm. thick, which in turn is overlain by a medium to coarse grained sandstone containing abundant large plant fragments. To the east in Danebower and Reeve Edge (N.G. SK 0125 6975) Quarries (Plate 10) and Blackclough only one continuous horizon has been observed, though sporadic occurrences of pellets appear approximately 1 m. below. All pellets measured in the Goyt area varied between 4 mm. - 2 cm. along their longest axis.

At Cracken Edge Quarries, three horizons occur, each from 9 cm. to 12 cm. thick. Two of them are associated with pink/brown mudstones and are themselves composed of pink pellets. The third horizon is associated with a coarse, massively cross-bedded sandstone and is composed of grey/green pellets ranging up to 3 cm. in length. The former horizons may be traced along the quarry face, the underlying mudstone diminishing to only a few centimetres sandwiched between thick cross-bedded sandstone, the lower bed of which is absent where the thick mudstone underlies the pellet horizon.

Mow Cop Quarry exhibits eight pellet horizons associated with a pale green/white mudstone horizon. All the pellets are pale green with a small amount of deep red staining around the outer 1 mm. - 2 mm. They range in size from 5 mm. to 15 mm. and are angular in shape, being in general not flattened. Mudstone pellets, though chocolate red in colour, were found at a similar level in the Alders Farm Borehole between 5½ m. and 7 m. from the top of the Rough Rock. In the lower part of the Rough Rock in Mow Cop Quarry (13 m. below the top), a band, 2 cm. thick, with sporadic, rounded, soft, chocolate coloured mudstone pellets occurred, the individual pellets being from 15 mm. to 18 mm. in diameter (Plate 11). They resemble small armoured mud-balls owing to the indentations of quartz grains. The majority of mudstone pellets are preserved in the base of medium scale, planar cross-bedded sandstone; a few occur in apparently horizontally bedded medium grained sandstone, though in places they have degenerated into unbedded sands owing to the high concentration of pellets.

Interpretation

The association of the pellets with medium scaled planar cross-bedded sandstone and the absence of quartzite pebbles suggests erosion and deposition in the lower flow regime. Absence of pellets in the majority of cases over the whole height of the set together with the small amount of grain indentation and the angular edges of the pellets suggests a short period of transport with the sandstone covering the pellets rather than the pellets being transported with the sand grains. The green/grey coloration of the pellets suggests that the parent mudstone remained below or near to the boundary of the water table prior to erosion.

LITHOFACIES 5 - Mudstone Conglomerates

Description

This lithofacies is confined to a small area 7 $km.^2$ in the upper Goyt Valley, represented by one, possibly two horizons. Outside this area a poor representative is observed 1 m. above the base of the Rough Rock in Wall Grange Brickpit, though the occurrences are only sporadic and thin and to some extent may fall within Lithofacies 6, Mixed Conglomerates. This lithofacies is gradational with Lithofacies 2, Mudstones and Siltstones, 9, Medium Scaled Cross-bedded Sandstone, and 10, Massively-bedded Sandstone.

It consists of discoidal and rod-shaped mudstone pebbles set in a matrix of medium to coarse grained sandstone, sometimes micaceous and plant rich. The included mudstone pebbles are dark purple to grey, lacking laminations, with planes of fissibility parallel to the general bedding of the enclosing sandstone. They range in size from 5 mm. x 1.5 mm. to 7 cm. x 1 cm. discs and 12.5 cm. x 4 cm. rods. Discoidal pebbles account for 73% of the whole, near-spherical pebbles for 4%, and irregular shaped for 0.8%, the rest being rod shaped. 243 pebbles were sampled. The dominant size of discoidal pebbles is 4.5 cm., while for rod shaped pebbles it is 6.5 cm. There is only a slight amount of grain indentation, though when observed in section large flakes of mica are seen to intrude into the mudstone. The enclosing sandstone is slightly cross-bedded, though it is not possible to judge the set thickness and angle of dip as the bedding planes are rough and highly irregular, occurring at approximately 15 cm. intervals.

The mudstone conglomerate horizon varies from 8 cm. to 2 m. thick. In the Goytsclough Quarry (N.G. SK 0120 7345) this variation is observed along a section of 150 m.; at the northern end of the quarry the conglomerate averages 1.25 m. with a channel 0.5 m. deep and 1.7 m. wide eroded into the underlying coarse massive sandstone (Plate 12). 50 m. to the south in the third embayment of the quarry, the conglomerate has thinned to 8 cm., lying between massive sandstone; a further 30 m. south-west in Deep Clough (N.G. SK 0122 7360) it is at least 12 cm. thick, though it may thin to 1 cm. - 2 cm. over a very short distance. To the north of these quarries the same horizon is observed 5 m. downstream from the small road-bridge and along the strike just above the level of the road to Errwood reservoir, where it is 1 m. thick and contains large plant fragments. Further north, the horizon is lost until Deep Clough (N.G. SK 0123 7614), south of the Intake (N.G. SK 0120 7648), and Issue Tor Quarry (N.G. SK 0116 7730) (Plate 13). At the former, a single horizon 10 cm. thick is seen, while at the latter there is one horizon of the same thickness, associated at the base of a cross-bedded sandstone which in turn is overlain by a pink mudstone and a 1 m. thick mudstone conglomerate. Throughout the Goyt section there appears to be a possibility that two conglomeratic horizons exist: apart from the Issue Tor locality mentioned above, the conglomerate at the northern end of Goytsclough Quarry is underlain by a massive sandstone with plant remains and occasional mudstone fragments and overlain by a cross-bedded sandstone, while in the southerly part, the conglomeratic horizon is overlain by a massive sandstone containing structures akin to cross-bedding and underlain by a massive sandstone. This may point to the presence of two separate horizons, the only other alternative being a rapid change in the overlying sandstone from planar cross-bedded in the north to fairly massive in the south.

The only other occurrence of this lithofacies is a sporadic band in Wall Grange Brickpit directly overlying the basal mixed conglomerate, and a relatively continuous band overlying a massively bedded sandstone and a cross-bedded sandstone at Cracken Edge Quarries.

<u>Interpretation</u>

Many workers have observed mudstone conglomerates in the field, but have merely given their origin as mudstone eroded from a nearby source. Allen (1962) observed intraformational mudstone conglomerates in the Devonian of the Welsh Borderland, and Kohls (1967) observed them in the Simsboro Formation of Texas. Both workers concluded that they represented the break-up by sand-laden rivers of an alluvial floodplain. In the Goyt area the presence of a channel and poorly cross-bedded sandstone packed with dark mudstone pebbles suggests that a strong sand-laden current invaded an area of soft plastic mudstone and churned it up into a mixture of sand and clay lumps, the final disposition of the clay lumps regulating their final form in the compacted and lithified conglomerate. In general, the rod shaped pebbles representing a larger original clay lump than the discoidal forms.

LITHOFACIES 6 - Mixed Conglomerates

Description

This lithofacies is confined to a distinctive level at the base of the Rough Rock, varying between 10 cm. and 2 m. in thickness. It is gradational with Lithofacies 2, Mudstones and Siltstones, 5, Mudstone Conglomerate, 9, Medium scale Cross-bedded Sandstone, and 10, Massive-bedded Sandstone, consisting of pebbles of both mudstone and hard rock, set in a matrix of coarse sandstone. The conglomerate is best seen at two localities: north of Moorside Hotel (N.G. SJ 9878 8290) (Plate 15) and Wall Grange Brickpit, the latter showing a section 150 m. long (Plates 16 and 17).

The pebbles are of two types: mudstone and 'rock', the former consisting of orange/red, purple or green/grey fragments from 3 mm. to 6 cm. long and inclined or parallel to the rough bedding planes; the planes of fissility, especially in the red pebbles are rarely parallel to the bedding, but rather to the shortest plane of symmetry of the fragment. The outlines are angular to sub-rounded and the shape is flakey to blocky. At Wall Grange, well-rounded red mudstone pebbles are common, the number of medium to fine sand-sized particles adhering to the pebbles being high, while at Moorside the pebbles are angular with few adhering grains; a large proportion of the mudstone fragments have been bent around large quartzite pebbles or ruptured by smaller clusters.

The pebbles are distinctively separated by colour, very little variation being observed within a pebble. Occasional red pebbles have a thin purple margin, though this rarely exceeds 1 mm. - 2 mm. for a pebble 2 cm. long. The green/grey pebbles have a little limonitic staining but this is common throughout the whole rock. At Wall Grange a light green variety occurs only as patches rather than bands.

The 'rock' pebbles are mainly quartzite, making up 91% of the group, metaquartzite and vein quartz being by far the most common; feldspar pebbles occur, some extremely fresh, others partly weathered, making up 8-8½% of the whole. Pebbles of igneous rocks and sedimentary rocks are rare. Three pebbles of porphyry and one polished pebble of possible sedimentary origin were extracted. Possible re-worked sandstone fragments have been observed at Wall Grange though this relies on colour variation against the host sandstone which could be due to iron staining from percolating solutions or decomposition of associated plant fragments.

The pebbles range up to 3 cm. long mainly sub-rounded to rounded, though a few are sub-angular; occasionally a well rounded pebble was observed that had been broken, one face being angular, the others being rounded.

The base of this lithofacies is very sharp, though the junction with the underlying mudstones may be erosive to a depth of 70 cm. Scour and fill features are abundant on the base of the sandstone, individual laminae being picked out as swirling lines and associated with drag marks, flutes and current crescents.

Plant fragments are exceedingly common throughout, the basal layers may be so crowded as to be termed plant fragment conglomerates. The fragments are better described as logs, up to 50 cm. long and 20 cm. thick, showing evidence of transport, having been eroded to such an extent that only occasional knots in the bark structure are visible, the linear markings in general being absent. They are only occasionally flattened, and many appear to be only in halves, being split as a bamboo cane may often do when soaked in water for a considerable time. Their presence is easily observed on account of the deep red coloration of the impressions.

<u>Interpretation</u>

Many workers have observed similar types of conglomerates at various stratigraphical horizons: Allen (1962) in the Lower Old Red Sandstone of England, Dineley (1960) and Friend (1965) in the Devonian of Spitsbergen, Doty & Hubert (1962) in the Pennsylvanian of the United States, and Bluck (1961) in the Lower Coal Measures of the South Wales Coalfield. All agreed that this lithofacies was deposited as a lag conglomerate after the initial erosion by a turbulent river of a flood plain.

The 'rock' pebbles by virtue of their rounded nature exhibit evidence of reworking of pebble-sized material from farther up-stream, and the presence of broken pebbles exhibits part of the process required for the formation of sand-sized particles, though much of this material was probably transported into the area as a sand-sized fraction derived from a flood-plain channel environment or coarse sediment 'reservoir' upstream from the area studied.

The mudstone pebbles show the colour variation of oxidation and reduction; the red oxidised examples appear in some cases to show evidence of being fairly solid before erosion took place. The clay content of the traction carpet was probably high, as the percentage of clay in the sandstone is relatively high, while most of the feldspars are fresh, few being rotted, so that defeldspathisation is ruled out as a possible source of clay.

Every feature of this lithofacies points to deposition from a sudden influx of water into a former tranquil environment, scouring out a channel and leaving as a residue a lag conglomerate composed of a variety of fairly local material derived from a cross-section of environments.

LITHOFACIES 7 - Pebble Seams

Description

This lithofacies is confined to a few distinctive bands in the lower part of the Rough Rock in the Potteries and Cheadle Coalfields, it being best observed at Rock Cottage (N.G. SK 0510 4663), near Moneystone, Foxt (N.G. SK 0558 4824) (Plate 18), between Brown Edge (N.G. SJ 9065 5388) and Hurst (N.G. SJ 9020 5940) (Plate 19), and Mow Cop Quarry (Plate 20). It is gradational with Lithofacies 9, Medium scale Cross-bedded Sandstone, consisting of layers or seams of dominantly quartz or quartzite pebbles ranging from 5 mm. to 4 cm. in length, being elongate to equidimensional and sub-angular to rounded.

They exhibit a variety of forms: single bands of one or two pebbles thickness, numerous bands at fairly regular intervals in close proximity to each other, pebble clots and pebble bands parallel to cross-bedding.

The first three forms appear to be genetically connected. The bands are one to two pebble layers thick, and lie on the erosive base of planar cross-bedded sandstone. In some cases up to four bands to 30 cm. occur making a pebble seam, between each band a planar cross-bedded sandstone, in the majority of cases devoid of included pebbles. At Mow Cop and Cawtons Well (N.G. SJ 9000 5550) some of the pebble bands thicken to four or five pebble diameters for a distance of 30 cm. - 60 cm., and then dwindle to their usual thickness, while in other cases pebble bands are seen on the base of successive sets, some of which blend into each other.

Interpretation

The transgressive nature and situation of the pebble bands in the erosive base of the cross-stratified sets indicates deposition from a fast flowing current, winnowing out the finer material and leaving a pebble layer on the erosive plane. The splitting of bands may be accounted for by the current cutting down through one set and encountering the lower pebble layer, while clots of pebbles would be formed in any depressions caused by overdeepening. Some pebbles may have originated from the erosion of pebbles from pebbly sandstone associated with occasional pebble bands.

The form occurring on foreset planes is due to avalanching of pebbles down the leeside or the buoyant effect of the finer material in the dune face: excess pebble material would roll down the face and be incorporated in the basal band, the band in this case being due to winnowing and/or avalanching. It is difficult to say whether the inversely graded nature of the cross-bedding is due to fluctuations in current strength or merely due to the buoyancy effect; as far as the pebble banding on the foresets in concerned the former mechanism is preferred, though to some extent this could be answered by fluctuations in the availability of pebbles, which in turn may be governed by the erosive strength of the current.

LITHOFACIES 8 - Contorted Sandstones

This lithofacies is gradational with Lithofacies 2, Mudstones and Siltstones; 3, Seat-earths, Ganisters, Ganisteroid Sandstones and Coal;

9, Medium-scale Cross-bedded Sandstone; 10, Massively-bedded Sandstones and 11, Ripple-bedded Sandstones. It consists of medium to coarse grained sandstones, the bedding or cross-bedding of which is contorted into symmetrical and/or asymmetrical folds, of a chaotic, twisted or flame-like form. It is dealt with here as a separate lithofacies owing to the possible existence of a single cause which has environmental and palaeogeographical significance. In the past, apart from the above name, it has also been termed convolute bedding (Frazier & Ozanik, 1961), corrugated (Shrock, 1948), deformed bedding (Rust 1968), and slumped sandstone, a name that the Geological Survey uses to date.

They occur fairly commonly in the Potteries area, while in the Goyt Trough Area they are only observed west of Fernilee Reservoir and around Birch Vale. In the eastern area they are restricted to the Coxbench area. The types of contorted bedding observed in these areas may be divided into four categories:-

(i) Flame-like anticlinal structures with broad synclinal structures.

(ii) Asymmetrically folded and associated with a thick set of planar cross-stratification.

(iii) Asymmetrical to symmetrical sharp folds associated with a curved erosive surface.

(iv) Small isolated exposures of flexures and deformations.

(v) Problematica.

Category iv appears to be associated with others. All the forms occur in graded cross-bedded sequences. Only at Coxbench Quarry is the grain size fairly uniform, although here dark laminations, rich in mica and carbonaceous material, typify the whole sequence. Décollement surfaces are absent.

(i) This type of contorted bedding is confined to Coxbench Quarry (N.G. SJ 3745 4345) (Plate 21), observed on the north-east face. Unfortunately, the face is vertical and bordered by water, and the study of the structures had to be carried out from photographs and examination of the cliff extremities. The sandstone consists of light grey/green fine-medium grained sandstone, cross-bedded to parallel-bedded, laminated micaceous, contorted into flame-like structures up to 3 m. in height, and a maximum of 1·5 m. wide. They appear as wisps in the upper layers, arising from parallel-bedded sandstone, the anticlines disrupting higher layers in the sandstone. In the lower layers, the contortions are associated with the cross-bedding, and form sharp crested, almost isoclinal, inclined anticlines with subsidiary bulbous protrusions, the cross-bedding being obliterated in places. The laminations are on the whole intact, though the scale and complexity of the contortions makes it difficult to follow individual laminations for any distance. The contortions occur in clusters with the intermediate bedding being relatively undisturbed.

(ii) This type of contorted sandstone is restricted to the north-eastern part of the North Staffordshire Coalfields, centred around

Cheadle. It is well exposed at Wall Grange Brickpit (Plate 22), Foxt (Plates 23 and 24), and Moneystone (Plate 25) where planar cross-bedded sets of up to 3 m. thickness are overlain by thinner sets of parallel-bedded sandstone up to 1·5 m. thick, though averaging 20 cm.

The contortions mainly affect the thicker cross-bedded sets, but where they occur towards the top and have high amplitudes they interfere with the thinner sets. The amplitudes range from 70 cm. to 1·5 m. the base being undisturbed. In between these two boundary planes the sandstone laminae are folded into symmetrical and asymmetrical anticlines, which in some cases have broken through adjacent laminae. The contorted bed horizons at all the localities are 3 m. - 5 m. above the erosive base of the Rough Rock, and at Foxt can be traced for over 100 m. at the same horizon. It seems likely that the horizon is present over most of the Cheadle area, but is unobservable at present, due to the freshness of the sandstones in the quarry sections. In all cases the contortions have steep limbs corresponding to the direction of dip of the cross-bedding, the axes of the folds being parallel to the strike of the cross-bedding. No example of truncation of the contorted sandstones was observed in this type of contortion. The example at Wall Grange is associated with steeply dipping cross-strata, the asymmetry of the deformations being exceedingly well-defined.

(iii) This type of contorted sandstone is observed between Brown Edge and Rock End in Staffordshire (Plates 26, 27 and 28), Coxbench Woods (N.G. SJ 3790 4320) and Morley Moor Quarries in Derbyshire (N.G. SJ 3872 4220) (Plate 29). It consists of symmetrical to slightly asymmetrical contortions associated with a curved scour-like plane on which slight indications of movement but no large-scale grooving is present. Within the sandstone mass bounded by the plane, a profusion of folds are visible, which have amplitudes from 17 cm. to 60 cm., being broad symmetrical to tight asymmetrical, and in general with the amplitude increasing upwards through the fold, successive laminations being affected to greater extents.

In the near vicinity of the contortions at Rock End are seen overturned cross-beds, both truncated and fully preserved, with smaller puckering or individual laminae only 120 cm. away from the overturned zones. At Gawton Well, an horizon of contorted strata is observed over a distance of 95 m. forming the top of the Rough Rock dip-slope.

At Morley Moor Quarries (Plates 29 and 30) contortions are observed in thin parallel-bedded sandstones along the erosive plane overlying planar cross-bedded, their general form is a symmetrical rounded fold up to 25 cm. in amplitude, though in detail the centre of the fold is composed of asymmetric sharp crested folds only 1 - 2 cm. in amplitude.

At Lodge Barn Farm (N.G. SJ 9000 5590) a spectacular form of contortion is observed in thickly-bedded (15 - 40 cm.), non-graded and poorly laminated sandstone (Plate 26). The scarp edge of the tor-like promontory exhibits cross-bedded sandstone with a thick semi-parallel-bedded sandstone 109 cm. from the top. The cross-bedding has a complicated form, being of a planar type, but with apparently tangential base and top. The angle of dip increases from 10° to 35° towards a shear-like plane, and parts of the sandstone toward the base of the thicker bed appear to be crumpled. The thick bed, though continuous over the apparent movement plane, is contorted into a monocline with dips of almost horizontal on the east to 50° on the west, a small fracture plane with a throw of only 3 cm. cutting through it 25 cm. to the west of the monoclinal crest, which has an axial plane direction of 348°, the movement plane being 330°. Overlying the thicker bed on the horizontal limb of the monocline is a set of unaffected planar cross-bedding, while on the steep limb of the monocline it is overlain by parallel-bedded, symmetrically contorted sandstones.

(iv) This type is observed at isolated localities with only a poor correlation with the other types. In general it consists of only small puckering but at Goytsclough Quarry and Lantern Pike it is present as an horizon with large scale deformation.

The small puckerings are mainly symmetrical round crested anticlines 5 cm. in amplitude, though slight asymmetry is observed occasionally. At Foxt an anticlinal flexure is observed to overlie a syncline with an undifferentiated mass in between: it is quite possible that both are anticlinal flexures, the anomaly being caused by the plane of section. Small puckering is observed on a well worn, almost polished face at Brown Edge (Plate 31), exhibiting a rounded symmetrical fold being overlain by an asymmetrical one. Above and slightly to the south (left) of this is a very broad slight flexure; this appears to be the first representative of the growth of a minor contortion, a continuation of the process being observed in Morley Moor Quarry, where a monoclinal flexure 5·7 cm. in amplitude is seen in thinly parallel bedded sandstone. Increased flowage would then form the asymmetrical type. Thickening over the crests in the coarser sandstone is easily observed in the well worn outcrop at Brown Edge, a feature which is visible in most contortions but which is difficult to perceive because of weathering.

The three-dimensional form of contorted sandstones is rarely observed: the general form perpendicular to the greatest plane of development appears to consist of gentle rounded anticlines with broad synclines. At Issue Tor, west of Fernilee Reservoir, a section is seen 50 m. to the south of the quarry exhibiting rounded anticlines and synclines of equal dimensions with an amplitude of 25 cm., the crests in places being truncated; perpendicular to this face is a similar display of contortions, with almost identical dimensions. In Issue Tor Quarry the same contorted horizon occurs in the flaggy layers high up in the quarry face - fallen blocks allow a close examination of the three-dimensional form of the structures. They appear as dome-like structures 20 cm. in diameter and 27 cm. in height, either interfering or blending with each other, or separated by sharp synclines; in the cross-sectional plane the synclines become broader downwards. The form shown in Plate 32 is a view of the underside of the contortions at a surface where the sharp anticlines give way to broader ones.

(v) Two cases of possible contorted sandstone occur in the area, the first being on the east face of Mow Cop Quarry half-way between the central boss and the south face (Plate 33), the second being in the top flaggy layers at Goytsclough Quarry (Plate 34).

At Mow Cop Quarry a sequence of white/green clay bands (see lithofacies 2) associated with medium grained, load casted, cross-bedded sandstone is observed to occur as a heterogeneous cross-bedded unit, the individual cross-beds having load casts where they rest on the interleaved clay. The top of this unit appears to be overturned in the south-westerly direction, load casts occurring on both the top and base of some of the cross-beds, though the basal surface load casts are better developed. The overturning dies out within 85 cm., the clay bands defining the overturned surface having been incorporated in the overlying sandstone.

In the flaggy sequence at Goytsclough Quarry large scoop-like structures with parallel bedding are observed; the largest structure 6 m. across is only seen in plane view, and may be associated with trough shaped cross-bedding, though this size would be by far the largest trough seen in the whole of the Rough Rock. The smaller, up to 2·5 m. across, are observed on the northerly corner of the first (southerly) bay. They are present for 6 m. in depth, after which they blend into the underlying medium/coarse fairly massive sandstone, below this there being a shale conglomerate horizon and a turbulently deposited sandstone with large shale blocks.

Interpretation

Contorted sandstones have been reported from many parts of the world, (Jones 1962, Rust 1968, Stewart, J.M. 1956, Friend 1965, Dineley

1960), and from numerous sandstone sequences in Great Britain (Selley 1969, 1964, Stewart, A.D. 1963, Allen, 1964, Broadhurst 1953, Mayhew 1966, Collinson 1967, Robson 1956). This work has been supplemented by experimental work and data from recent deposits (McKee, Reynolds & Baker, 1962, Selley & Shearman, 1962, together with data from engineering practice.

The general concensus of opinion from the above studies may be summarised:-

(i) Seismic origin

(ii) Differential compaction

(iii) Overloading

(iv) Current drag

(v) Falling water level

(vi) Quicksand action - Rising water level, saturation

Observations in the Rough Rock show that these possible origins are well founded, though falling water level (Jones 1962, p.238), causing decrease in pore-water pressure would make the sand more stable as more of the individual grains would come into contact; any movement, due to removal of the top of the slope, in the semi-dry state, would cause fractures rather than folds. All the forms observed in the Rough Rock show laminae being continuous in and around the fold, except where the structure is diapiric, and rupture of laminae has occurred in the upper layers. It must be assumed therefore that movement took place in a wet state with the sand deformation being plastic, much of the movement being concentrated on the coarse bands; since they are thicker over anticlinal flexures, which acted like a sheet of ball bearings, owing to the high void ratio compared to the finer grain above and below: the majority of contorted sandstones observed being in graded cross-bedded sections tends to support this. Furthermore, it may be assumed that deformation occurred soon after the initial deposition, as in many cases the bed above the deformed bed is planar and erosive, and in some cases the deformations themselves are truncated.

Overloading causing deformed sandstones would have to be associated with rapid deposition which would occur in times of flood. In the Rough Rock, only two examples of contortions due to possible overloading are observed, Wall Grange and Lantern Pike. Both are associated with steeply dipping cross strata (40°), though only at the former is a channel feature in close proximity. At the latter locality, the underlying sandstone is planar cross-bedded sets with horizontally bedded sandstone forming erosive tops to some, the contorted sandstone horizon being visible for 150 m., the northern section having gentle flexures in low angle cross-bedding, while the southern section shows a progressive increase in the scale, amplitude and asymmetry of the contortions in a increasingly steep dipping cross-bedded sandstone.

The occurrence of contorted sandstone due to differential compaction in a local area is limited to the locality in Goytsclough Quarry, the gentle scoop-shaped deformation in the flaggy upper beds of the quarry could be due to the presence, 30 m. below, of shale and shale conglomerate bands, together with a castically-bedded coarse sandstone. Compaction of the underlying beds would cause disturbance at a higher level: this would give an answer to the apparent dying out of the trough-like bedding downwards.

The presence of small-scale but complex contortions associated with channel bases, shale conglomerates and chaotically bedded sandstone at Goytsclough Quarry and Cracken Edge points to an origin of the turbulent current puckering and contorting the sandstones over which it flows. The sands presumably would be completely covered by the sediment-laden water and frictional forces would be high.

Many of the above types of contortions may have been produced in the semi-wet to completely saturated (quick) state. This latter state appears to be the primary environment for the formation of distorted bedding, providing all the necessary physical requirements stated. The previous examples and respective interpretations are based on genetic criteria most of which are debatable, owing to the absence of comparable recent structures and experimental data. The majority of deformations have asymmetric folds or flame-like folds, and are often associated with planes of discordance. The recent opinion concerning these deformations is that they were formed when the sand was in a 'quick' state, the pore-water pressure being high, and movement assisted by clay floccules or coarse bands acting as pore-water channel-ways. In the Rough Rock, grading and appreciable clay content are present through the whole, there being no significant increase in the deformed horizons.

Seismic origins as a sole cause are discounted for the Rough Rock examples. The absence of sedimentary dykes, contemporaneous faulting and sandblows, together with the apparent absence over large areas seems to point to an alternative origin, though an initial seismic movement could trigger off so many other processes, such as water-table fluctuations, large-scale slumps, channel diversions and increase in shape, that any features directly related to seismic activity would be masked or obliterated.

The plastic nature of flow is accounted for by the sand being fully saturated due to a heightening of the water table outside the main channel, and a rapidly deposited sandstone undergoing repacking caused by a turbulent channel flow. The recumbent cross-beds were formed by the overriding force of a sand mass pushed forward by strong currents over a quicksand, the thixotropic nature of which decreased downwards. McKee, Reynolds and Baker (1966) proved this experimentally, and Rust (1968) observed scour features slightly upstream from the recumbent structures in the Tertiary of Canada. A similar origin is inferred for the contortions at Foxt, and the drag structures at Morley Moor Quarry, though at the latter the layer of quicksand is completely contorted and appears incorporated into the overlying bed; the association at this locality of the contortions with curved planes of apparent discordance tends to modify the simple explanation of quicksand movement, it being unsuitable as the cause of the whole structure. It appears that failure has occurred along a curved plane of weakness, possibly due to a pore-water effect, and that normal deformation has taken place in the foundered block. The monoclinal structure near Cawtons Well may well be the upper limit of this plane of failure. The area distribution of the contortions in the Stoke-on-Trent area falls on a straight line between Mow Cop Quarry and Oakamoor; though this could point to a structural line of weakness or environmental boundary, it was felt that the distribution could easily have been due to the sparcity of outcrop to the south-west and the absence of outcrop to the north-east.

To summarise, all the types of contortions were probably formed while the sand was in a wet or 'quick' state, and though the reason for the apparently sudden appearance of this state cannot be pinpointed, it is highly probable that other structures and processes were produced by it, which also play a part in the production of deformed sandstone. Recently Casagrande (1971) has observed flow slides due to liquefaction of river sands in the point bars of the Mississippi River and in earthquake prone zones of Alaska.

LITHOFACIES 9 - Medium-scaled, Cross-bedded Strata

Description

This lithofacies is by far the most common in the Rough Rock of the area studied and is gradational with all others, except Lithofacies 1. The grain-size varies between fine/medium and coarse, and pebbles up to 3 cms. in diameter occur in some sets (see p.73) (Plate 35), together with plant fragments (Plate 36), logs (Plate 37) and mud granules (Plate 38). The latter are often associated with sandstones representative of lithofacies 4 and 5. Modal analyses on sandstones from this lithofacies shows it to have an apparent composition of feldspathic sandstone or sub-arkose. The high matrix content of some sandstones may be due to defeldspathization, though the presence of clay pellets, conglomerates and detrital clay particles point to an abundance of clay available for deposition, especially in the Goyt Trough area, and in the lower horizons of the Rough Rock in the Stoke-on-Trent area. Part of the clay matrix is undoubtedly due to rotting of feldspars, as clay is observed to pseudomorph feldspar or the feldspar (especially orthoclase) is observed to be in an advanced state of decomposition. The amount of clay matrix due to defeldspathization is probably appreciably lower than has previously been thought (Evans et al. 1968).

The detrital grain shape is bimodal, grains larger than 0·5 mm. are subangular to sub-rounded while smaller grains are angular. Fine grained sandstones are well sorted, while coarser sandstones tend towards moderate to poor sorting.

Calcite cemented sandstone is observed in the Goyt Trough and Sheffield area and is mainly confined to concretions in more massively bedded sandstone with poorly developed cross-bedding (Plate 39). Barker, M.J. (pers. comm.) and Hardy (1970) have concluded from the study of concretions in the Coal Measures of Lancashire that they are due to the localisation of calcite from comminuted pelecypod shells. No reliable conclusion can be made as shell debris is absent, only trace fossils proving their original existence.

The main textural and mineralogical features of the Rough Rock parallel those in other Upper Namurian sandstones, where quartz overgrowths, sutured and straight grain contacts, etc. occur in profusion. Therefore, for the sake of brevity and posterity the reader is referred to the following authors: Collinson (1967), Mayhew (1966), Greensmith (1957), Gilligan (1920), Shackleton (1962) and Wright, M.D. (1964) (the discussions and conclusions of most, differing little from those of Sorby (1858)).

The sandstone is cross-bedded throughout in sets of up to 4 m. in thickness. The sets may be tabular or trough-shaped, either type occurring in cosets up to 12.5 m. thick. Occasionally cosets of both types are found, in which case the trough sets are generally found above the tabular. Although both types are gradational and have many features in common, they will be described separately.

(1) Tabular shaped cross-beds

Tabular sets of cross-strata are by far the most common representatives of cross-bedding in the Rough Rock. It is unusual to visit any outcrop of Rough Rock without observing some evidence of tabular cross-bedding in the immediate vicinity. According to Allen (1968), large scale tabular sets are not widely reported, having been recorded previously only by McDowell (1957), Fahrig (1961), Shackleton (1962), Potter (1963), Harms and Fahrenstock (1965) and Simons and Hopkins (1966). More recently they have been noted by, amongst others, Collinson (1967) and Bluck (1961) in British Upper Carboniferous sandstones.

Three basic types of tabular cross-beds occur in Rough Rock, which tend to have both a restricted areal and vertical distribution.

(a) Thick medium-scaled sets

The term 'thick' has been used in order that no confusion would arise between these cross-beds and Collinson's Large-Scale Cross-beds, which attain a thickness of up to 26 metres.

Thick, medium-scaled sets are generally restricted to the lower half of the Rough Rock in the western part of the area studied (Plates 23 & 40). They consist of up to 3 metres of fine, well sorted sandstone or medium to coarse sandstone; the latter predominating in the Stoke-on-Trent (Plate 43) and Cheadle areas, with randomly distributed pebbles. Individual cross-beds rarely exceed 5 cms. and have truncated tops and erosive straight bases (Plate 41). The set is often isolated from any underlying sets by parallel bedded sandstone, which itself may attain a thickness of over 1 metre. Within this type of cross-bedding large-scale contortions are developed and appear to be restricted.

At Foxt the only occurrence of back-set ripples observed in the Rough Rock was present at the base of a 2·5 metre thick set and lie on a parallel bedded sandstone. The ripples attained heights of 7 cms. and were directed in the opposite direction to the cross-bedding (Plate 42).

In the southern Goyt Trough area, thick medium scaled cross-bedding is present towards the base of the Rough Rock, below the shale conglomerate horizons. They are observed at Reeve Edge Quarry, Danebower Quarry (Plate 10), in a roadside exposure by Errwood Bridge (Plate 45), in the cliff exposure south-west of Errwood Dam (Plate 44) and at Issue Tor Quarry (Plate 13). Unlike the examples in the Stoke-on-Trent area, the Goyt examples rarely show grading or well-developed individual cross-beds. The foreset plane is more steeply inclined than in other types of cross-bedding and reaches a maximum of 32°, with associated primary current lineations down the foreset slope. At Issue Tor Quarry wood fragments up to 2 metres long (Plate 37) are observed lying on the foreset planes parallel to the primary current lineation.

The full lateral extent of this type of cross-bedding is difficult to assess, it appears that continuity in excess of 7 km. occurs in the Goyt Trough area. In the Stoke-on-Trent and Cheadle area, as noted in the Foxt boreholes, the cross-bedding is not capable of correlation between closely spaced boreholes (Fig.6), although north of Brown Edge it can be traced in isolated outcrops for up to 500 m.

<u>(b) Medium-scaled cross-bedding with associated parallel bedding</u>

This type of cross-bedding is restricted to the upper part of the Rough Rock in the south-west Pennine area; notably at Rock End, Stoke-on-Trent (Plate 46), and Stake Edge in the Goyt (Plate 47). It is characterised by individual cross-bedded sets, up to 1 metre thick, with cross-beds up to 1 cm. thick, sandwiched between an apparently parallel-bedded sandstone of a similar thickness. A slight variation of the basic type is present at Mow Cop Quarry and the Cat and Fiddle Quarry, where shale and siltstone bands have replaced the parallel-bedded sandstone (Plate 6). Small concretions are common in this type of cross-bedding, although fossil material is generally absent except for poorly developed leaf impressions.

The associated parallel-bedded sandstone may to some extent be rippled, as observed at Moneystone Quarry and Bilinge Hill Quarry. As with other lithofacies, the effects of weathering tend to mash the detailed morphology of the beds, which even when fresh fail to exhibit indicative features.

The lateral extent of this type of cross-bedding is greater than 100 m. and may reach 500 m. with only slight variations in thickness. This fact is apparent from tracing the outcrops of cross-bedding on Stake Edge and Brown Edge, although when borehole information from Foxt and Moneystone is considered, it appears that this type of cross-bedding may be a local feature.

(c) Medium-scaled tabular cross-beds

This type of tabular cross-bedding is the most common found in Carboniferous sandstones, having featured in most of the theses and publications on the Namurian and Westphalian. In the Rough Rock they may represent a link between the thick cross-beds and the cross-beds with associated parallel beds. Throughout the Rough Rock there are few exposures showing more than four or five sets. Parts of the Hurst Quarry and Cracken Edge Quarry exhibit well developed sets and cosets, but the most instructive exposure is in Danebower Quarry (Plates 10 and 49).

The sets are up to 1 metre thick, with individual cross-beds varying between 1 cm. and 7 cm. thick. It is difficult to measure the thickness of cosets, but at Danebower Quarry and Moneystone Quarry, cosets are observed up to 6 m. thick without any intercalation of other lithofacies types. The upper surface of the sets is always erosive, while the basal surface may be planar or tangential (Plate 50); in the latter case the three-dimensional form tends towards trough-shaped cross-bedding.

The great majority of exposures exhibit sets with parallel or relatively parallel tops and bases. At Danebower Quarry, there is a tendency for the sets to thicken and thin within the limits of the 41 m. face. The best example of this feature is observed in the lower half of the eastern face (Plate 49), where a set thickens from 11 cm. to 30 cm. within 2 m., and finally thins to its original 11 cm. This feature may represent a partly eroded dune, but the apparent stoss side appears a little too steep when compared with Allen's average slope of 8°. On the other hand, it may represent the sides of a channel running obliquely to the exposed face.

(2) Trough-shaped cross-beds

Trough-shaped cross-bedded sets are uncommon in the Rough Rock, being far less important than tabular-shaped sets. This is in complete contrast to their relative importance in sandstones in the Carboniferous above and below the Rough Rock horizon.

The sets observed rarely exceed 1 m. in thickness, the majority being 30 cm. to 60 cm. thick. Individual cross-beds vary from 1 cm. to 6 cm. in thickness, and there appears to be a slight correlation between set thickness, cross-bed thickness and grain-size. This is illustrated by comparing the sets at the bottom of Goyts Lane with sets at Billinge Hill Quarries. At the former locality, the sets are over 1 metre thick, with 6 cm. thick, coarse-grained cross-beds, while at the latter locality the sets are up to 60 cm. thick, with 1 cm. to 2 cm. thick fine-grained cross-beds.

Owing to the lack of outcrops exhibiting trough-shaped cross-bedding, it is difficult to assess the coset thickness. From the limited outcrops in the Goyt area, it appears that generally isolated cosets occur which may attain 8 m. in thickness. Correlation between exposures does not exist, and each set observed is isolated in both lateral and vertical extent.

The most common type of trough-shaped set is observed at Goyts Lane (Plate 51), in the southern embayment and road-side sections at Goytsclough Quarry (Plate 52), and at Billinge Hill Quarry. This type consists of a coset up to 3 m. thick, composed of up to four scoop-shaped sets. Individual cross-beds vary from 6 cm. in the coarse-grained sandstones at Goyts Lane to 1 cm. - 2 cm. in fine to medium-grained sandstones at Billinge Hill and Goytsclough Quarry. At Goyts Lane, red shale pellets are common in the cross-beds, while at Bilinge Hill the cross-beds have micaceous surfaces with common organic-rich plant impressions.

This common form compares with Allen's sinuous and lingoid ripples at a small climb.

The only other type of trough-shaped cross-bedding is observed in the lowermost beds of the Rough Rock in the old quarry at Billinge Hill (Plates 53 & 54). It consists of a 8 m. thick coset composed of sets up to 40 cm. thick, and individual cross-beds up to 2 cm. thick. This type of cross-bedding compares closely with Allen's description of cross-stratification generated by sinuous or linguoid ripple-trains at a steep climb.

Finally, the unusual type of bedding observed in the uppermost beds at Goytsclough Quarry, which have previously been described (in Lithofacies 8 - Contorted Bedding), may represent a trough-bedded set (Plate 34). They compare to some extent with cross-stratification generated by sinuous or linguoid ripples at a steep climb. Unfortunately, the only exposure is in the inaccessible top beds of the quarry and any conclusion must rest between a contorted bed or trough-shaped cross-bed theory.

<u>Interpretation</u>

The only reliable conclusion that can be gained from the study of the cross-beds in the Rough Rock, and, to all intents and purposes, in all none Recent sandstones, is that they were formed by flow in the upper part of the lower flow regime. This conclusion regarding a combination of both water depth and velocity in fluvial systems and flume studies was reached by Simons and Richardson (1965) and Harms and Fahrenstock (1965).

Although the recognition of the flow-regime is an important feature of any interpretation, depth of water and velocity are the prime features, as it is the combination of both of these parameters which is recognised, but not quantified, in the flow regime.

The study of trough-shaped cross-bedding has added little to the knowledge of depth of water of the depositing stream, since there is a clash of view as to their mode of formation.

Harms and Fahrenstock (1965) believe that trough-shaped cross-bedding is due to the deposition of a fill into an erosion hollow or scoop in the stream bed. Thus the height of trough-bedding would not depend on the depth of water. On the other hand, Allen (1963) and Reineck (1960, 1963) believe that trough-shaped cross-bedding is due to the migration of certain three-dimensional forms of largescale ripples, in which case the height of the set would be proportional to the depth of water. Neither theory has yet been proved, and an estimate of minimum water (height = depth/6) can be made only on Allen's theories with regard to trough-shaped cross-bedding(Yalin 1964).

In the case of the Rough Rock, the water depth varies between 6 m. for the coarse-grained sets, and 2·5 m. to 3·0 m. for the fine-grained sets in the Goyts Lane and Goytsclough Quarry areas.

The study of the tabular-shaped cross-bedding yields more information than that of trough-shaped cross-bedding. Allen (1969) and Harms and Fahrenstock (1965) both agree that this type of cross-bedding is due to the migration of straight-crested dunes. It thus becomes possible to estimate the minimum depth of the depositing stream, using Yalin's equation. For the tabular sets in the Rough Rock, the depth varies from 1·2 m. to 4·0 m. in the upper part, to 24 m. in the lower part. McKee (1957) and Jopling (1963) studied the internal organisation of tabular cross-bedding, and observed that the angle of cross-bed dip and the angle it makes with the lower bounding surface are dependent on the velocity of the depositing stream.

McKee, studying tabular cross-beds in flume experiments, noted that steep foresets were formed at low flow velocities, especially when the sand was composed of coarse angular grains and had a low clay content.

Jopling (1963), also using flume experiments as his base, showed that a sigmoidal foreset profile was associated with a high depth ratio, and that the dip of the foreset could be reduced by an increase in flow velocity.

Allen (1965) studied the surface texture of the foreset flumes, and showed that the lineations, akin to the parting lineation in plane beds, may be explained by low flows causing discrete avalanching down the lee side of the dunes.

The study of the cross-bedding in the Rough Rock has shown that the majority of cross-beds were deposited by a low velocity stream in a shallow-to-moderate depth of water. Only in the lower beds could the streams be classed as deep, and only in the northern and north-western areas do the structures show an indication of increased water flow.

LITHOFACIES 10 - Massive Bedded Sandstones

Description

Massive bedded sandstones are gradational with all lithofacies types. It is highly probable that although they appear in the field to be massive, internal structures are present but do not generally manifest themselves on weathered surfaces (Allen, 1971). The two localities at which this lithofacies is observed are Wall Grange Brickpit and Goytsclough Quarry.

At Wall Grange Brickpit this lithofacies occurs at the base of the exposed Rough Rock either resting directly upon the red siltstones and shales or separated from them by a basal conglomerate of shale pebbles, quartzite pebbles and log fragments. Over most of the quarry-section the lithofacies consists of medium grained, poorly sorted sub-arkose to arkose with no immediate structure visible; however, in zones bordering major joints, a weak planar cross-bedded sequence is observed, while to the northern end of the quarry a 'contorted' zone may form the upper part of the lithofacies. The cross-bedding is not graded or micaceous as is the majority of cross-bedding observed, and this may cause the lack of discernible weathering characteristics.

In the Goytsclough Quarry section the massive bedded sandstones are observed at quarry floor level in the northern part of the quarry (Plate 55). Close to the former mill-stream, this lithofacies is a 4 metre thick, poorly sorted sub-arkose with occasional carbonate concretions in what is for the most part a structureless sequence. The only discernible structure present is a lens shaped trough-bedded set in the centre of the northerly face and possible large planar cross beds at the easterly corner of the embayment. The latter structure may be the channel edge face, as, only 20 metres to the east, at the same stratigraphic horizon, in the small hillock by the road, a ripple and cross-bedded lithofacies is observed.

50 metres to the north in the northern embayment of the quarry there outcrops in the opening below quarry-floor level a definite example of this lithofacies (Plate 56). The sandstone is coarse structureless and friable containing contorted lenses and blocks of shale, together with log fragments and shale flakes. In general, it has a knolled appearance. At the entrance to the opening the massive bed is seen cutting into a shale and siltstone sequence, the boundary being vertical, though some shale layers have been eroded preferentially.

Further representatives of this lithofacies are possibly present along the road and stream running northwards towards Errwood Reservoir, and may be equivalent to the thick tabular cross-beds at Errwood Reservoir Cliff, Issue Tor Quarry and Danebower Quarry.

Interpretation

The lack of diagnostic internal structures restricts interpretation to the use of lithofacies boundary features and types of included fragments. From these features, it is clear that the massive bedded sandstones were deposited by a powerful current, capable of eroding and carrying shale and coarse sand material and depositing the load in structureless masses over fairly restricted areas. The only environments suitable in this situation would be a main channel or flood channel environment.

LITHOFACIES 11 - Ripple-bedded Sandstone

Description

Ripple-bedded sandstone is gradational with all other lithofacies except lithofacies 6 - Mixed Conglomerates. It is possibly much more common than is at first realised owing to the effect of weathering which has masked the external characteristics of thinly-bedded sandstones.

The lithofacies is generally restricted to fine-grained sandstones, although at Errwood Reservoir Bridge one exposure shows rippled, medium grained sandstone. Over the area studied two types of ripple structure have been observed, trough-shaped ripples and symmetrical to slightly asymmetrical, straight-crested ripples. The former type is by far the most common.

Trough-shaped, ripple-bedding is not restricted to any one area or to any one horizon. It is best developed, in the lowermost Rough Rock at Billinge Hill, throughout the Rough Rock north of Ridgeway Quarry, near Ambergate and at Mellor, and as intermittent bands in the Cat and Fiddle area and at Moneystone Quarry (Plate 57). It consists of trough-shaped sets up to 4 cms. thick and cosets up to 4 metres thick, composed of fine grained sandstone. Individual ripple beds are separated by concentrations of micaceous and carbonaceous laminae up to 3 mm. thick.

At an exposure below Errwood Reservoir Bridge a medium grained, trough-shaped, ripple-bedded sandstone is observed with sets up to 12 cms. (Plate 58) thick and with relatively poorly developed micaceous and carbonaceous laminae. This example tends towards a medium-scale, trough-shaped, cross-bedded sandstone.

Straight-crested ripple-bedding has been observed at only two localities, 100 metres north of the re-sited Old Goyts Bridge (Plate 59) and at Ridgeway Quarry (Plate 60), near Ambergate. It consists of symmetrical to slightly asymmetrical, straight-crested, ripples with heights of up to 2 cm. and amplitudes of 6 cm. to 7 cm. Parting is facilitated by occasional laminations of very fine, silty and clayey sandstone overlying the rippled surface. The sandstone is generally free from micaceous and carbonaceous material and is clearer and often finer grained than the trough-shaped ripple bedding.

Interpretation

Ripple-bedding (small-scale, cross lamination) is characteristic of flow in the lower part of the lower flow regime.

Trough-shaped ripple-bedding is due to the migration of linguoid or lunate ripples under conditions of net sedimentation, the dark laminae are due to the deposition in the ripple trough of grains of lower hydraulic radius.

The straight-crested ripples are thought to be indicative of wave oscillation in tidal flat or lake environments. In the two examples observed in the Rough Rock the wave formation is possible as poorly developed flaserschichten are present and Hardy (1970) studying the orientation of trace fossils in the Goyt area implied a tidal environment.

LITHOFACIES 12 - Parallel bedded Sandstone

This lithofacies is gradational with all other lithofacies types and is best developed in the lowermost and uppermost parts of the Rough Rock. It is possible that it may contain in part structures indicative of lithofacies 9 and lithofacies 11, the difficulty in distinction again being due to weathering characteristics masking the primary sedimentary structures, as was the case in lithofacies 10 and 11.

Parallel-bedded sandstones are best observed at Goyts Lane in the lower section of the Rough Rock, 100 yds north of the resited Old Goyts Bridge in the upper section (Plate 61), at Hall Broom Quarry throughout the section at Cracken Edge (Plate 62) and as a thin development of the Rough Rock at Consall. Other examples at Coalpit Ford Farm and Ambergate Brickpit are less well exposed.

At Goyts Lane the parallel-bedded sandstones are observed overlying grey siltstones and shales on the north bank of the stream entering Errwood Reservoir. Overlying the parallel-bedded sandstone at this locality is a series of trough-shaped cross-beds composed of coarse, clay rich sandstone. The parallel-beds attain a composite thickness of up to 3·5 metres, though individually they average 25 cms and are separated by thin, 4 cms thick, bands of siltstone. The base of the sandstone is occasionally load-casted into the underlying shale and siltstones, while the top of the sandstone is rarely straight being usually affected by small scale undulations and indentations akin to a mixture of ripples and trace-fossils, which have no regular patterns or shape. The sandstone itself appears internally structureless, and is usually fine-grained and contains varying amounts of shale debris, often coarse near the base and of dark red and green shale, while towards the top only medium-grained red clay particles occur.

In the stream cliff 30 metres south of Goyts Bridge (Plate 61) the upper part of the Rough Rock consists of 5 metres of parallel-bedded sandstones, each bed averaging 10 cm thickness and separated from other beds by a thin, 1 cm, band of silt. The majority of the beds appear structureless having straight tops and bases; on the other hand on one bedding plane exposed by stream erosion an asymmetrical straight crested oscillatory ripple system is exposed on the upper surface (Plate 59). It seems probable that this sequence of parallel-bedding may in fact be ripple-bedding but due to the state of weathering and of the exposure, the structures are usually masked.

At Hall Broom Quarry the Rough Rock exposed in the north face consists of 10 metres of parallel-bedded flagstones, each bed on average being 3 cms thick. On both the upper and lower surfaces of the beds current lineation is a dominant feature, while internally the bed is observed to be finely laminated, the laminae being picked out by mica rich layers, the lamina thickness in some cases being only a few grain diameters thick. Occasional planar to tangential cross-bedding sequences are present in the quarry but the dominant sandstone is the parallel-bedded sequence.

The most unusual sequence of parallel-bedded sandstone composing the entire thickness of the Rough Rock, is the 3 metre thick band of green/grey horizontally laminated sandstone at Consall (GR.SJ97924816). This sandstone consists of a micaceous and carbonaceous siltstone and fine grained sandstone, individual beds averaging 70 cm and individual laminae averaging 3 mm. Apart from the horizontal laminations the sandstone is relatively structureless, the base and tops of the individual beds being straight. On the top are occasional plant fragments, in the form of leaf and stem impressions of Calamites. They are in general well preserved and rarely exceed a few centimetres in length. This and the Cracken Edge locality are the only localities where small plant debris occurs.

At Cracken Edge the sandstone sequence is split by a thin discontinuous shale band in the southern embayments of the quarry, while in the northern embayments the lower sandstone has been replaced by a parallel-bedded sandstone and shale sequence. This feature was first noted by Wright (1964) and the author has found no reason to change the overall feature observed by Wright. The parallel-bedded sandstone is a pale green/grey, occasionally often ripple bedded. Though usually horizontal laminated fine grained sandstone (Plate 62), the lower surface is weakly load-casted into the underlying shales and siltstones, the upper surface is often marked by the trails of Pelecypodicnus(Plates 63 & 64), while internally symmetrical vertical burrows are common. One such bed can be traced from the top of the lower sandstone in the northern part of the quarry into the lowermost beds of the upper sandstone and into the underlying parallel bedded sandstone in the southern part of the quarry. The localities at which trace-fossils were observed in the Rough Rock are generally restricted to the parallel-bedded sandstones in the north western part of the area studied. The reader is referred to Hardy (1970) for detailed information regarding the Pelecypodicnus trails, to whom a list of the trace-fossil localities in this area were supplied.

Interpretation

The parallel-bedded sandstones observed in the Rough Rock may be attributed to two types of environment. It seems likely that the types associated with ripples as in the Goyt Valley and to some extent Cracken Edge fall into the Ripple-Bedded Facies with a lower flow regime and possible overbank or low river stage environment. The difficulty in categorising is due to weathering characteristics. The other localities show completely contrasting environments for this lithofacies.

At Brown Edge Quarry the thin well laminated flags with abundant clearly developed primary current lineation suggest that the flowwas in the lower part of the upper flow regime (Allen, 1964 and Simons et al. 1965), and in an environment closely related to the main channel flow, possibly a shallow part where, due to decrease in depth, a low current velocity would give structures indicative of upper flow regime.

In contrast the localities at Consall and over part of Cracken Edge exhibit well laminated, burrowed, fine grained sandstone with small-scale plant material and an upper surface showing *Pelecypodicnus* trails, together with an association of shales and siltstone. These structures indicate a low flow regime with little sediment movement giving good conditions for the survival of *Pelecypodicnus* and the accumulation of organic material on which they fed.

Chapter 6

Palaeocurrent Directions

The Rough Rock abounds with structures from which palaeocurrent data can be extracted. In the majority of cases orientations were obtained from planar cross-bedding, but supplementary data in areas where planar cross-bedding was absent were obtained from plant fragments, trough-shaped cross-bedding, current crescents, ripple-bedding and primary current lineation. Previously published data, within the stratigraphic range of interest, on the area studied are few and except for Shackleton's work (see Chapter 7), are recorded where they assist in the formulation of an areal pattern, (see Fig.7).

In the eastern part of the Potteries Coalfield, the Cheadle Coalfield and the Western and Southern parts of the Goyt Trough, the planar cross-bedding has very little deviation when separate limbs of the syncline are studied. The Potteries and Cheadle areas show current directions from the east (87°) and north-east (39°) respectively while in the western and southern Goyt Trough, which is the nearest outcrop moving north-east, the current directions are from the completely opposing direction of west (272°) and south-west (231°). The intervening area between these contrasting directions has no exposed Rough Rock and is dominated by the Triassic filled Rudyard Valley, being part of a roughly north-south running syncline. In the basal parts of the Rough Rock along the edge of these two main exposed areas (eg. Rock End and Wall Grange), and in occasional isolated exposures, there is a representative of a southerly to south-easterly direction which is also observed north of Derby at Morley Moor Farm. In the latter area as one moves northward the current direction moves round from east to south-east and in many ways is a mirror image of the southern end of the Goyt Trough, in the vicinity of Goldsitch Moss.

The general pattern of flow obtained from planar cross-bedding in the southern part of the area studied appears to be a poorly represented primary flow from east/south-east with a secondary flow having contrasting directions on either side of the primary flow, ie. a flow from the south and west to the north of the primary flow, and from the north-east and east to the south.

On top of this general pattern may be placed the orientation data obtained from wood fragments, ripple-bedding and axial dip of contorted strata, the latter being of dubius value.

Log fragment orientation measured at the base of the Rough Rock, at Wall Grange gave a mean direction of 347°-167° with a 20° range, and at Rock End gave a mean direction of 3°-183° with a range of 14°. This general paralleling of planar cross-bedding direction was also present in the roadside quarry near Danebower where a well-exposed surface of log debris showed a mean current direction of 21°-191° with a range of 32°. Small secondary means at 90° to the primary means were present at all three localities. At Consall the orientation of small plant fragments and leaf stems failed to give a good overall direction though the most prominent direction was 93°-273°.

Ripple-bedding had very similar directions to the planar cross-bedding, at Rock End the mean was 273° and at Moneystone 192°. The wave-oscillation ripples at Ambergate had a direction of 158°-338° against 299° for cross-bedding, while at Goyts Bridge the ripple direction was 170°, almost parallel to the general cross-bedding data immediately to the south.

The validity of orientation data from contorted beds has never been discussed before, but it is highly probable that the direction of slumping, ie. the direction of steepest asymmetry in the fold, would point down the local palaeoslope. In the Potteries and Cheadle Coalfields area this direction is to the south and west while at the southern extremity of the Derbyshire Coalfield it is to the north. Both these directions parallel the direction obtained from other well-established palaeocurrent indicators and normal to the direction of the poorly discernible primary flow.

Within this southern area there is only one small area which somewhat clashes with the general pattern, this area being the western limb of the Potteries Coalfield from Mow Cop to The Cloud. Along the outcrop of this limb the current direction has a mean of 34° with a range of 235°, dominantly to the eastern segment. The importance of this sudden and isolated change will be discussed later (Chapters 8 and 9); it remains here only to point out that the area differs from neighbouring areas not only through current direction properties but also in facies type and position in relationship to major structures which have affected sedimentation throughout the Namurian.

Overall, the area south of a general line from Bollington to Ambergate, cutting the Goyt Valley at Errwood and Burbage Edge, exhibits the above. The central area of this southerly system, either side of which the palaeocurrents diverge, is placed roughly along the line of the Widmerpool and North Staffs Gulf (Kent,1966).

Moving northward to Disley, Hayfield and Whaley Bridge, still on the limbs of the Goyt Syncline and complimentary Kettleshulme Anticline, to the west an opposing north-easterly current direction is present, separated from localities exhibiting a north-westerly current by poor outcrop. Although the overall direction in this northern area is from the north-east, there is a localised easterly component along the eastern limb of the Goyt Syncline, while on the limbs of the Kettleshulme Anticline to the west the current trend is from the north and north-west. These northern areas studied possibly represent a second primary direction of flow from the north-west; this is in agreement with Sorby's, Gilligan's and Shackleton's works, having weak representatives of secondary flow to the south. At Cracken Edge and Moorside Lodge the cross-bedding is well developed and the Rough Rock thicker than to the north or south. Although the evidence is not strong, it appears that the central line of flow from the north-east runs approximately between Kinderscout and Macclesfield.

Between the contrasting current directions at the northern and southern ends of the Goyt Syncline lies a central complex area in the vicinity of Errwood Reservoir, forming the central part of the Goyt Syncline and having no exposed connections with the outcrops on the limbs. The current directions in this area may be described as chaotic, the direction changing erratically from outcrop to outcrop, with no discernible pattern. The Goytsclough Quarry section shows current directions from both a northerly and southerly direction with the former being predominate; the directional importance of the wavy structures which may be a deposited or contorted structure, is not known. Moving north from Goytsclough Quarry differences in direction may be observed in almost every outcrop, while around the shores of Errwood Reservoir and Fernilee Reservoir the palaeocurrents, especially when only the thick tabular sets are considered, box the compass. It is felt that the southerly component in the Fernilee area represents a secondary flow of the primary north-east to south-west flow. While the northerly component near Errwood represents a secondary flow of the primary east to north-west flow. The area may, therefore, be regarded as an area exhibiting violent mixing of the two systems.

On the eastern borders of the Pennines between Sheffield and Derby, the Rough Rock is generally very poorly exposed, a feature which tends to mask the fact that it is very thin and restricted to a flaggy often parallel or ripple-bedded sandstone.

In the Sheffield to Chatsworth area, the dominant palaeocurrent direction is from the north-east, with secondary from the north. While north of Derby the flow is from the east with secondary flows from the south. In both areas the data are heavily weighted with orientations taken from structures other than tabular cross-bedding. In general, the variation in thickness of the Rough Rock together with the areal distribution of lithofacies reveals more in the interpretations of palaeocurrent directions than the orientation data.

It is hoped that the use of first order cross-bedding, over which, in certain areas, the lower orders of ripple-bedding, plant orientation and primary current lineations have been placed, has set the palaeocurrent data in an integrated form. By doing this the overall pattern of two major dispersal systems is exhibited throughout the hierarchy of bed forms. At this point it is worthwhile to add to the above data the palaeocurrent directions obtained by other workers from closely associated arenaceous and fossiliferous horizons in sequences above and below the Rough Rock.

Heptonstall (1964) studied the Gastrioceras cancellatum Marine Band at two localities within the area studied here, Orchard Farm, at the southern end of the Goyt Trough, and Biddulph on the eastern edge of the Potteries Coalfield. At the former locality palaeocurrent directions obtained from fifty goniatite ventors and plant stems exhibited a very variable current which appeared to have flowed more often from the east than from any other direction. At the latter locality directions obtained from 220 measurements again exhibited a variable current which for most of the time flowed from either the north or south.

Haslam (1966) attempted a similar study in the Gastrioceras cumbriense Marine Band at Higher Disley and Pott Shrigley. The current directions from the two localities again exhibited a variable direction. At Higher Disley the overall pattern of flow appeared to be from either the north-west or south-east, and although a similar pattern was observed at Pott Shrigley there was also a second mode at right angles to the former direction.

P. Hardy (1970) studied trace-fossil material from the Upper Namurian and Lower Westphalian, and included information from three localities within the southern Pennine area. At Goyts Moss, Billinge Hill and Cracken Edge, he used the orientation of Rhizocorallium, Pelecypodichnus and Cochlichnus respectively, as indications of palaeocurrent direction. In all the cases of interest to this study, he used data obtained from loose material and therefore was unable to correlate the orientations with true bearings; instead he used the term 'arbitrary north'.

At the northern localities of Billinge Hill and Cracken Edge he noted a single current direction which in the former case may be from the north to north-east and in the latter case may be from the east to south-east, using a correlation with sandstone directional properties from this thesis.

In contrast, the currents in the Goyts Moss area flowed from two completely opposing directions, which, through correlation with the work in this thesis are possible almost due north and due south.

It is of interest that both sedimentary features and fossil features give similar current directions over the area studied, this being most apparent in the southern Goyt.

Finally, palaeocurrent directions from the sandstones immediately above and below the Rough Rock - ie. the Woodhead Hill Rock and the Holcombe Brook Grit - are added to the picture to observe whether the directions obtained from the Rough Rock are an isolated feature restricted to the Rough Rock. Both sandstones have only been studied in detail in the south-eastern Pennines, and therefore current data from the south-western Pennines were taken by the author.

Mayhew (1966) obtained current directions on the Ashover Grit indicating current directions from the east over almost the whole length of outcrop from Sheffield to Derby, there being a slight northerly component in the south. In the south-western Pennines the author found a generally contrasting state of affairs to that in the Rough Rock. In the Goyt and north Potteries Coalfield areas the current direction was from the east, while in the more southerly Shaffalong and Cheadle Coalfields the current was from the north-east.

Guion (1971) investigated the Woodhead Hill Rock along the eastern outcrop of the southern Pennines from Sheffield to Derby. North of Baslow, the observed current directions were from the north-east and east, while south of Baslow the current moved round to flow from the south-east. Although the Woodhead Hill Rock is much better developed than the Rough Rock of the south-eastern Pennines, the overall picture is very similar.

In the south-western Pennines the author observed a similar state of affairs to that in the Rough Rock, the Woodhead Hill Rock again being relatively better developed than to the east. In the Potteries area the current was from the north-east, while in the southern Goyt the direction was from due south, there being no westerly component, similar to that observed in the Rough Rock. This may be due to the fact that the Woodhead Hill Rock only outcrops in the centre of the syncline. The southerly component was traced as far north as Fernilee, which is three/four miles farther north than the definite southerly component in the Rough Rock. In the far north of the area studied, in the Disley/Hayfield area, the direction has again reverted to from the east. This scanty picture of the Woodhead Hill Rock shows a definite similarity with the underlying Rough Rock, while the Holcombe Brook Grit, which in turn underlies the Rough Rock, shows little similarity.

It thus appears that over a relatively thin stratigraphical range on either side of the Namurian/Westphalian boundary a dual current system is observed in both sandstone and fossiliferous shale deposits; unfortunately, the all-important Gastrioceras subcrenatum Marine Band has not yet been studied.

The general features of the palaeocurrent directions are the major north-west and south-east sources and the diverging directions on each side of the primary flow. When the whole area is considered, the directions almost box-the-compass; only the north-west quadrant having a low density, although the spread for any part of the area is very low.

Doeglas (1962) considers that a low spread of current directions is indicative of braided rivers. In the Rough Rock the great majority of the outcrop data, especially in the southern half of the area studied, are possibly not representative of a river channel system but merely a view of an intimately associated neighbouring environment. It is, therefore, unlikely that the low spread of palaeocurrent direction over fairly large parts of the area can be used as an indication of a braided river system being present in the area studied.

Chapter 7

The Work of J.S. Shackleton

J.S. Shackleton was a research student at Liverpool University until his untimely death in 1961. From his notes, data cards, maps and microscope slides, Drs. A.D. Stewart and R.G.C. Bathhurst produced a paper entitled 'Cross-strata of the Rough Rock (Millstone Grit Series) in the Pennines', which appeared in the Liverpool and Manchester Geological Journal for 1962.

Shackleton was the first to study the palaeocurrent systems of a single sandstone over such a large area of England, though this type of study had been carried out on a large scale in the United States by Potter et al. (1958), Pelletier (1958) and Yeakel (1959). His study covered an area of 4,000 square miles and included 301 localities from which 1,738 measurements of cross-stratal orientation were taken. Unlike the work of the Americans which was concerned with large outcrop areas coupled with sub-surface data, the Rough Rock of Shackleton's study is mainly exposed as a ribbon outcrop with few sub-surface data, and, therefore, it was impossible to adopt a close-grid system. This is borne out by comparing Grid D (455 readings) with Grid (K)(27 readings). To some extent, Shackleton's data collection points were too sparse, especially in the southern part of his area, though this may have been due to the large area surveyed. In most cases his sampling points coincided with the dip arrows shown on the 1 inch Geological Survey sheets, with only few data from intervening areas.

The large size of Shackleton's area appears to have been the major stumbling block indirectly affecting the validity of his work. The study of the Rough Rock depends upon the recognition of the confining marine bands G. cancellatum, and G. subcrenatum, and although this fact is recognised in his posthumous paper it appears that he did not isolate the individual horizons at localities within his area but merely relied upon the Geological Survey maps of the time. This was a very dangerous assumption since the Stockport (98), Chapel-en-le-Frith (99), Macclesfield (110), Leek (111), Stoke-on-Trent (123), Ashbourne (124), Chesterfield (112), and Derby (125) 1 inch Geological Survey sheets were published before the stratigraphical value of goniatites was first appreciated by Bisat, and therefore were not subject to reliable stratigraphic control. In general, except for the area around Stoke-on-Trent and Sheffield, south of Northing 390 it was the Woodhead Hill/ Crawshaw Sandstone from which data were taken. Due to the averaging technique of rose diagrams associated with 20 km square grids, used in the diagrammatical representation of the palaeocurrent data, only Grid K remains valid, Grids I, J, L and M embracing, in part or wholly, a sandstone other than the Rough Rock, (see Fig.8).

The lithological boundaries of the Rough Rock are also affected by the inaccurate correlation. The northern boundary between Conglomerate and Pebbly Sandstone together with the north-eastern part of the Pebbly Sandstone/Non-pebbly Sandstone boundary appear to be correct, though the south-western part of the latter passes through the centre of Grid I in which 85% of the data collected was from the Woodhead Hill Rock. A similar state of affairs applies to the Conglomerate/Non-pebbly Sandstone boundary in the south-east, while the northern part lies along the line delineating the change from Crawshaw Sandstone and corresponding to the junction between the Sheffield and Chesterfield 1 inch Geological Survey sheets.

The data included in the text, apart from cross-stratal dip orientation are obviously suspect. Of these data the percentage error of the modal analyses, set thickness and frequency of cross-stratal dips can be calculated. Unfortunately, it is impossible to do the same with the grain size analyses. Of the 1738 observations used to construct the set-thickness and cross-stratal dip frequency histograms, 171 or 9·84% were invalid, and of the 62 thin sections used to provide data for the QFM diagram, 5 or 8·1% were invalid, only two samples south of grid line 390, both of which were from the Sheffield area, being reliable.

The southern half of Shackleton's area appears to have been of only minor importance, supplying 227 (13·1%) out of 1738 observations, and only 7 (11·9%) out of 62 thin section analyses; part of this can be assigned to the lesser area of outcrop and poor exposure.

Shackleton's work has been quoted extensively in many major sedimentological works (Potter and Pettijohn 1963, and Allen, J.R.L. 1968) and his results are taken as confirmation of Sorby's and Gilligan's earlier works, indicating a current flowing from a general north-easterly direction. The results of the present investigation invalidate part of Shackleton's work. For this reason the author has extracted the valid information from Shackleton's personal notes, slides, etc. and combined it with that of his own, in order to construct a palaeocurrent map and QFM diagram capable of portraying the regional pattern in the Central Pennines.

The value of this type of synthesis is that it not only provides a palaeocurrent map for a single arenaceous formation over the greater part of the Central Province (only data from Flintshire, North Yorkshire and North Lancashire being absent), but also provides the author with a significant amount of information to the north and possibly upstream of his own area.

The results are shown in Enc.6. It will be noticed that the lithological Pebbly Sandstone/Non-pebbly Sandstone boundary of Shackleton is placed slightly north of the 390 Grid line and that the whole of the southern area consists of Non-pebbly Sandstone, except for local accumulations near the base and a few pebble bands higher up in the sandstone. Very little significance can be placed on these boundaries as any local variations which exist within the northern area have not been surveyed by the author. From the modal analysis QFM diagram it will be seen that the results from the southern area show a higher percentage of clay and other minerals in comparison to the northern area. This may be due to either decomposition of the feldspars during transport from the north to the south or to the presence of a separate channel system in the southern area depositing material of a relatively more mature composition. The palaeocurrent map when viewed overall tends to depart from the conclusions of Sorby and Gilligan in that the direction from which the currents flowed is from every point other than from the west, the greatest variation being in the south. When the current pattern is compared with the isopachyte map for the Lower Coal Measures (Wills 1956, fig.2) and account taken of the results laid out in Chapter 6, the presence of an area of greater subsidence broadly around Stockport towards which currents tended to flow becomes a possibility.

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Section 3

SPECULATIONS

Chapter 8

Lithofacies Associations

Introduction

The various lithofacies described in Chapter 5 are each indicative of the local depositional process which existed at the time of their formation. In addition further information is available from palaeocurrent data and to a lesser extent from petrological data (Chapter 6). All of this unco-ordinated information refers to the processes operative in a restricted vertical and areal field. In this Chapter and Chapter 9 (Conclusions) the information is grouped into associations indicative of large-scale sedimentary environments which in turn are part of a major sedimentary and palaeogeographical framework.

In certain areas (Mow Cop and Brown Edge) it is only possible to assign a particular group of lithofacies to an association after weighting with 'known' palaeogeographical information. The recognition of lithofacies associations necessitates comparison with recent sedimentary environments and processes which have generally only been studied in plan and on a relatively small scale. In contrast this study has drawn information from a wide area and a thick, possibly diachronous unit, in which the base and top of the unit are rarely exposed. This has meant that small scale and detail was locally abandoned in favour of obtaining an overall picture of the palaeogeography, which could be supplemented by additional data as they become available.

In considering lithofacies associations in the Upper Carboniferous of the Southern Pennines, most researchers have used a combination of deltaic, coastal plain and fluvial frameworks, into which the associations are fitted, although only Walker (1966) and Collinson (1967a)in the Kinderscout area have substantiated conclusions which fit not only the sedimentary framework but also the tectonic framework. This latter feature cannot be divorced from any study in the Southern Pennines although recent researches in the Namurian R_2 (Mayhew 1966) and the Westphalian A(G_2) (Guion 1971) have concentrated more on the sedimentary framework, which has led to the palaeogeographical conclusions in part clashing with the proven tectonic framework outlined by Falcon and Kent (1960) and Howitt and Brunstrom (1966). This in turn casts doubt on their assumed sedimentary framework.

Recent deltas and coastal plains have been studied extensively but the majority of the work has centred around the facies developments of the delta-top areas. Much of the work in depth has been carried out by petroleum companies whose personnel have produced many papers on the sedimentary sequences and stratigraphy but only outlined the main structural features of delta sedimentation, owing to the economic importance of this latter type of information. In 1971 two papers were published on the Southern Nigerian Basin which indicated the extent to which tectonic features have governed facies development (Murat 1971), and also the extent of synsedimentary faulting in the

Niger Delta Basin (Merki 1971). Merki, although only taking information from the Niger, states that synsedimentary faults are well known in world wide Cenozoic deltas. This statement may in the future affect the interpretation of past palaeo-delta studies, and shows up the shortcomings of pure lithofacies studies and their application to major sedimentary frameworks.

Similarly the study of fluviatile deposits has been restricted to small areas of major rivers and the research has centred around specific features of the fluviatile system (i.e. sedimentary structures and current directions). However, in 1969, Coleman analysed a large area of the lower reaches of the Brahmaputra River and described in some detail both the channel and overbank deposits. Unfortunately no information is as yet available on the effect of tectonics on the location of major channels, save for the fact that the Hwang Ho and Yangtse in the Peoples Republic of China have abruptly changed their courses in historical times.

In the present study the writer believes that the Rough Rock in the Southern Pennines is broadly fluviatile, and only to the north and possibly west of the area is a deltaic framework feasible.

Fluviatile Association

The fluviatile association is the dominant feature of the Rough Rock, volumetrically by far the most important, and is the only association represented, apart from the Chesterfield area and thin bands in the Goyt Valley. It includes rocks ranging from basal mixed conglomerates to pale green/white kaolinite mudstones and appears to contain many of the major units observed in recent fluviatile systems, though in many cases the dividing line between the different systems is far from clearly defined.

The association may be divided into three sub-associations:

(a) Channel

(b) Avulsion/Overbank

(c) Flood Channel.

(a) Channel Sub-Association

This sub-association consists of the following lithofacies:

6 Mixed Conglomerate

7 Pebbly Sandstone

8ii Contorted Bedding

9i(a) Thick Medium-scaled Cross-Beds

9ii(c) Medium-scaled Tabular Cross-Beds,

and is recognised by a sharp, erosive, basal contact with the underlying shales and mudstones, a basal mixed conglomerate and a fining upwards sequence.

It has been extensively described from Namurian and Westphalian arenaceous sediments, and it is generally assumed that all of the thick 'grits' in the Upper Namurian and Lower Westphalian are broadly channel deposits.

In the Rough Rock of the area studied, it mostly occupies the basal and mid-sections and grades upwards and laterally into the Avulsion/Overbank sub-association. Only at Wall Grange Brickpit does a near complete section of the Rough Rock appear to be composed entirely of the Channel sub-association (Plate 17). Apart from the above definitive features, a slightly increased variance of the cross-bedding orientations is noticeable and may be an indicative feature.

At Wall Grange the basal mixed conglomerate contains rounded and angular, red and grey mudstone cobbles and pebbles and log fragments overlying with slight angular unconformity pink and grey mudstones and thin siltstones, which are locally contorted immediately below the contact. Overlying the basal conglomerate, which attains 70 cms. thickness, are thick medium-scaled cross-beds up to 6 metres thick and with isolated asymmetric contortions (Plate 22). Two sets are immediately discernible, while a third grades upwards into tabular, medium-scaled cross-beds which in the highest beds observed become weakly trough-shaped. Cross-bedding direction is to the north-west but has a spread of 103°. There is no apparent preferred direction or steady change in direction from base to top.

To the north-west and south-east of Wall Grange only isolated partial exposures of the sub-association are visible. At Noonsun Common and Whiston, tabular cross-beds overlie basal, pebbly, tabular cross-beds resting on pink mudstone, while at Wetley Rocks, Werrington, Baddeley Edge and Stockton Brook tabular medium-scaled cross-beds which tend towards a trough shape have minor channels up to 40 cms. deep within the sequence.

In the north of the area studied (Goyt Valley and Sheffield) representatives of the Channel sub-association are observed at Moorside Lodge, Cracken Edge and Bradfield Moor.

At Moorside Lodge (Plates 15 and 65) a more complex development of the Rough Rock occurs than that at Wall Grange, though the laterally equivalent sections are also present, which are not observed at Wall Grange. The basal mixed conglomerate overlies grey shaly mudstones and contains inter alia angular red mudstones, pebbles and large log fragments. It is immediately overlain by 1.7 metres of massive bedded, pebbly, medium to coarse grained sandstone containing red mudstone granules. This sandstone grades upwards into 1.1 metres of fine to medium grained, parallel-bedded sandstone with local tabular-bedded zones, on which rests a 0.45 metre thick, intraformational mixed conglomerate. The conglomerate represents the basal section of a channel fill, which has over the extent of the outcrop (80 metres) cut into the underlying channel sequence by 0.42 metres, and merges with the overlying coarse to medium grained, apparently planar cross-bedded sandstone. Palaeocurrent data from the massive beds suggest that the planar cross-beds may be part of a large-scale scoop with a long axis sub-parallel to the Goyt Valley; if this is not the case there would appear to be a major reversal of flow towards the east, which is contrary to other local trends. The upper channel sandstone grades into planar medium-scaled cross-beds which have a similar current direction to the underlying massive beds. North of Moorside Lodge towards Disley and south towards Taxal the uppermost planar cross-beds are still visible, though they become finer-grained, but the massive sandstones appear to die out (from feature mapping) and a channel width of no more than 0.8 kilometres is feasible. Between Taxal and Hoo Moor the Rough Rock fails completely (Stevenson 1971).

Almost due east of Moorside Lodge on the opposing limb of the Goyt Syncline at Cracken Edge a complicated series of flaggy sandstones is developed in which a channel sub-association is present. The complication arises from the presence of a well developed flaggy sequence generally taken to represent the Rough Rock Flags (Stevenson op. cit.) which occurs below a flaggy development of the Rough Rock. Wright (1964) has described the sequence and observed a channel boundary in the sixth embayment (south to north). It is doubtful whether this is a channel boundary, as the sudden appearance of a mudstone intercalated between flaggy sandstones in the seventh embayment can be traced southwards, with difficulty, into a poorly developed mudstone pellet conglomerate.

In the first and second embayments (southernmost) and along the slope leading from the lane to Chinley, a channel sub-association bearing similarities to that at Moorside Lodge is exposed and cuts into the presumed Rough Rock Flags. The mixed conglomerate is devoid of red mudstone pebbles and the sandy matrix and overlying massive beds are finer grained (fine to medium) than at Moorside; however, the overlying planar cross-beds are identical. It is difficult to assess the number of superimposed channels present at Cracken Edge, owing to the similarity of the arenaceous deposits in the Rough Rock Flags and the Rough Rock, but as only one is clearly visible it must be assumed that localised thin mudstone pebble and pellet conglomerates, present in the massive beds, are related to the same channel.

In the Sheffield area outcrops are isolated and separated by relatively extensive exposureless moorland. At Hollow Meadows and Rivelin Side on the south of Rod Moor 7.5 metres of massive to pebbly, tabular, medium-scale cross-bedded sandstone are observed with intercalated fine to medium grained tabular medium-scaled cross-beds and overlain by fine-grained horizontally-bedded flags. The massive sandstone units each attain a thickness of at least 4 metres and at Hollow Meadows the lower beds contain occasional log fragments and mudstone pebbles. On the north edge of Rod Moor at Hall Broom Quarry a 5 metre coset of tabular medium scaled cross-beds occurs towards the top of the Rough Rock and presumably overlies beds equivalent to the upper massive sandstone to the south. At Ringinglow Quarry on the southern edge of Hallam Moor, 8 metres of micaceous parallel-bedded, flaggy sandstones are exposed, in which the middle 3 metres appears to be more massive with poorly defined planar cross-beds and rests on the underlying flags with very slight unconformity. East of Ringinglow Quarry a 2 metres section in the more massive flags with poor cross-stratification overlies 1 metre of parallel bedded micaceous sandstone resting conformably on grey mudstone, while south of Hallam Moor flaggy planar medium scaled cross-bedded sequences outcrop at Hallfield Farm and north of Grouse Inn. Palaeocurrent data over the Sheffield area is sparsely distributed and directions change widely from outcrop to outcrop. At Hall Broom Quarry, near the top of the Rough Rock, the direction is from due north while on the south of Rod Moor it is from the easterly quarter, only to revert back to north in the outcrops at Hallam Moor and farther south.

Finally in the North Staffordshire Coalfield numerous outcrops may be deemed to include representatives of the Channel sub-association due to their juxtaposition with beds characteristic of the other fluviatile sub-associations. Between Lions Paw and Hurst the Rough Rock can be divided into an upper and a lower unit on the marked variation in lithofacies and by a more subtle variation in palaeocurrent direction. The upper unit is assigned to the Avulsion/Overbank sub-association while the lower unit is presumed to be representative of channel deposition. It consists of a basal pebbly, coarse-grained, massive sandstone which locally exhibits poorly developed tabular cross-bedding with weak contortions, overlying pink mudstone or soft structureless medium to fine grained sandstone typical of the 'Rough Rock Flags' in the Potteries area. The pebbly basal beds are succeeded gradationally by thick, medium scaled cross-bedded to massive sandstone (Plate 40) with included isolated, randomly distributed contortions. The palaeocurrent data of this lower unit is far more variable than the upper (63^{o} spread) and has a more northerly mean direction (303^{o}).

In the Foxt area numerous boreholes (Fig. 6) put down by British Industrial Sands Company Limited have helped to delineate the boundaries of the Channel sub-association as a sharp, steeply inclined feature abutting against beds representative of the Avulsion/Overbank sub-association. Boreholes 3, 6 and 9, situated 400 metres north-west of Town Head (N.G. SK 0385 4900) proved coarse sandstone overlying red marl and a general fining upwards sequence (B/H. 3). On the other hand, Boreholes 5 and 8, 300 metres south-west of Town Head, proved alternating bands of sandstone and shale or micaceous sandstone and a much diminished thickness, while south-east of Foxt highly contorted sandstones occur (Plates 23, 24 and 41) in a sequence of massive, parallel-bedded and thick, tabular cross-bedded sandstone, all representative of the Avulsion/Overbank sub-association. The presence of channel deposits is also supported by isolated outcrops, in the old quarry north of Town Head and the massive and weakly contorted sandstones at Moneystone, and by outcrops previously mentioned (p. 132) at Wiston and Noonsun Common.

(b) Avulsion/Overbank Sub-Association

This sub-association consists of the following lithofacies:

2	Mudstones and Siltstones
4	Shale-pellet Conglomerate
7	Pebble Seams
8(iii)	Contorted Sandstone
9(1)a	Thick medium scaled Cross-Beds
9(1)b	Medium scaled tabular Cross-Beds with associated parallel beds
9(1)c	Medium scaled tabular Cross-Beds
11	Ripple-bedded Sandstone
12	Parallel-bedded Sandstone

In its simple form, as at Coxbench, it is characterised by the down dip gradation from contorted sandstone with semi-circular 'slip' planes and medium scaled cross-beds with associated tabular cross-beds through a sequence of medium scaled cross-beds with occasionally intercalated ripple-bedded sandstone, to a thin arenaceous sequence of alternating parallel- and ripple-bedded sandstone with associated shale and mudstone bands. However, in the North Staffordshire Coalfields and the southern Goyt area the sequence has been modified by the interplay of converging sandstone sheets and the intrusion of 'channels' into overbank areas. The necessity of a sub-association outside that of the Channel sub-association is required to explain the opposing palaeocurrent data of the Quarnford and Cat and Fiddle

Inn area with the eastern limb of the Potteries Syncline, and to a lesser extent between the two limbs of the Potteries Syncline. Hence the direction of palaeocurrents is an additional indicator of the sub-association when viewed regionally rather than locally (Fig. 7 and Enc. 7).

In the Coxbench to Ambergate area, contorted sandstones, with semi-circular slip planes and their associated massive to thick, medium-scaled cross-bedded sandstones outcrop at Marley Moor and behind the Fox and Hounds Inn, Coxbench, and in both cases are overlain, with sharp disconformity, by a series of medium-scaled tabular cross-bedded sandstones and parallel-bedded sandstones (Plate 29). Adjacent to these sections in Coxbench Quarry the Rough Rock is observed in a 20 metre face as a development of fine-grained sandstone with flame-like contortions in which only four bedding planes are discernible, and only the lowest bed exposed exhibits cross-bedding (thick, medium-scaled cross-beds).

North of the Fox and Hounds Inn to Belper, the sub-association is represented by 9.5 metres of parallel-bedded and tabular, medium-scaled, cross-bedded, medium to fine grained sandstones, which tend to become massively bedded towards the base.

Further north to Ridgeway Quarry, the Rough Rock thins to approximately 6 metres of which only 2.9 metres is exposed, consisting of 2.4 metres of fine-grained parallel-bedded sandstone overlain by ripple-bedded sandstone and the Gastrioceras subcrenatum Marine Band (lingula/fish fauna).

From Ridgeway north to Linhay, only ripple- and parallel-bedded, fine-grained sandstones and siltstones are developed, which reach 17 metres in thickness in Ambergate railway cutting before thinning to 10 metres at Fritchley and finally feathering out north of Linhay into only 2.6 metres at Alton, Holymoorside and Bar Brook.

Palaeocurrent data in the south Derbyshire area prove a progressive swing from the east to the south-east and south along the outcrop from Coxbench northwards. The eastern derivation is pronounced only in the lower beds at Marley Moor and Coxbench, while the northerly flow is proved by the dip of the slip-plane in the contorted sandstones and by the overlying cross-bedded sandstones.

On the northern limb of the Cheadle Coalfield at Town Head, Foxt and Moneystone the sub-association is more complex and involves two distinct sequences of avulsion/overbank sedimentation.

West of Town Head (see p. 137), boreholes 5 and 8 (Fig. 6) proved 14 metres of alternating thin beds of micaceous sandstone and red 'marl'. At Moneystone Quarry boreholes (Crowtrees No. 8, GT and GW) and face exposures prove a maximum of 30 metres of alternating fine to medium-grained, parallel-bedded and weakly, tabular, cross-bedded sandstones and red 'marls' and fine-grained micaceous sandstones and siltstones.

In the intervening area at Foxt and Wiston 15 metres of thick, medium-scaled cross-beds with complex contortions (see p. 137) are overlain by 8 metres of thick, medium-scaled cross-beds with included parallel-bedded and tabular, medium-scaled, cross-bedded sandstones.

Palaeocurrent data from cross-bedding and contortions in the Foxt and Wiston area are very strongly towards the south and have a very low spread (179^{o} - 194^{o}), while at Moneystone the direction is dominantly to the south-west (190^{o} - 208^{o}) with occasional reversals, problematic very large scale scoops and a much higher variance. Data are unobtainable at the Town Head localities but the similarity of lithofacies suggests an equivalent mode of deposition, though the reason for a thinner development cannot be suitably answered.

In the northern half of the Potteries Coalfield the areal distribution of the sub-association is less clear due to the paucity of sub-surface data but it appears to have a similar development to that in the Cheadle Coalfield.

At Lions Paw, Cawton's Well, Lodge Barn (Plate 26), Rock End (Plates 27 and 28) and Biddulph Moor, on the eastern limb of the syncline, contorted sandstones with semi-circular slip planes are overlain disconformably by 6 to 8 metres of tabular, medium-scaled cross-beds with associated parallel beds. Immediately above the erosive contact the cross-beds are locally thick.

Palaeocurrent data of both the contortions and the cross-beds are very strongly towards the west (273°) and spread is only 10°, though to the south of the above localities a slight swing towards the south-west quarter develops; to the north the swing is to the north-west, parallelling the palaeocurrent directions in the lower unit.

On the opposite limb of the syncline at Mow Cop an 8 metre exposure consists entirely of tabular, medium-scaled cross-beds with a strong current direction to the west (250° - 274°).

North of Mow Cop Quarry on Congleton Edge the sub-association is represented by a basal 3.5 metre series of tabular medium-scaled cross-beds with included pebble seams (Plate 20) resting conformably on structureless, leached sandstones, exceeding 4 metres in thickness and containing localised horizons of rounded, chocolate marl pebbles and white clay bands. The basal pebble seams are identical to those exposed at Foxt (Plate 18) and Cawton's Well (Plate 19), and are assumed to be at an equivalent horizon. Overlying the pebbly cross-beds is a single, 4.5 metre set of thick, medium-scaled, cross-bedded sandstone (Plate 43), equivalent to but less well developed than exposures below the contortions at Rock End, Knypersley Park and Cawton's Well, which in turn is overlain by an alternating series of parallel-bedded sandstones and pale green/white mudstones (Plate 6), locally exhibiting load casting and mudstone pellet horizons. This series is dominant for a thickness of 2.5 metres, above which it blends into tabular, locally contorted, medium-scaled cross-beds which infill very large-scale scoops (Plate 43), and in which sets and individual foreset planes are separated by pale green mudstones. Towards the top of the Rough Rock the set thickness increases, the mudstone density decreases and cream orthoquartzites are developed.

Palaeocurrent data at Mow Cop Quarry and Mow Lane Quarries indicate currents flowing from the north and north-west, with only occasional incursions from the east, the latter being restricted to the section above the parallel-bedded sandstones and mudstones, especially in the orthoquartzites.

At Timbersbrook the log of the Alders Farm Borehole (Cope 1948) indicates intraformational mudstone conglomerates between 3.5 metres and 6.5 metres below the top of the Rough Rock, a position which correlates with the mudstone horizons in Mow Cop Quarry and the top of the contortions at Rock End.

In the south-western limb and nose of the Goyt Trough, a mirror-image development of the sub-association in the Potteries Coalfield occurs. At Goldsitch Moss and Quarnford the whole thickness of the Rough Rock (28 metres) consists of tabular, medium-scaled cross-beds exhibiting a strong palaeocurrent flow from the west ($74^{\circ} - 87^{\circ}$), and by the bridge at Goldsitch Houses poorly discernible channelling occurs approximately 6 metres below the top.

North of Goldsitch the sub-association is exposed in the Scours area as a lower unit of tabular, medium-scaled cross-bedded sandstone and parallel-bedded sandstone, in which channels up to 0.5 metres deep occur, separated from an upper ripple- and parallel-bedded fine-grained sandstone unit by fossiliferous shales and mudstones.

From the Cat and Fiddle Inn northwards along Stake Edge, a further lateral gradation occurs (i.e. perpendicular to the predominate palaeo-current direction). In the road-side quarry a 5 metre thick, alternating sequence of tabular, cross-bedded fine-grained sandstones and thin shales, siltstones and micaceous danstones is exposed, while on Stake Edge 3.5 metres of tabular cross-beds outcrop (Plate 47). These exposures appear to be stratigraphically equivalent to the upper unit at The Scours, no lower unit being exposed. In all cases the palaeo-current direction is from the west.

(c) Flood Channel Sub-association

This sub-association consists of the following lithofacies:

4	Shale pellet conglomerate
5	Mudstone conglomerate
9(1)a	Tabular, thick, medium-scaled, cross-bedded sandstone
9(1)c	Medium-scaled, tabular cross-beds
9(2)	Trough-shaped cross-beds
10	Massive-bedded Sandstone
11	Ripple-bedded Sandstone
12	Parallel-bedded Sandstone

It is regionally characterised by the lateral gradation of lithofacies and the opposing, linear orientation of palaeocurrent data in the Goyt Valley between Orchard Farm in the south and Fernilee in the north, and by the thick development of mudstone conglomerate bands and massive sandstones between Goytsclough Quarry and Issue Tor. This contrasts with the development of mudstone pellet conglomerate horizons and a thinner arenaceous sequence around the limbs.

The sub-association is exemplified by three sections across the Goyt Syncline.

In the Roadside Quarry at Danebower (Plate 8), towards the top of the scarp feature, a 1.5 metre alternating sequence of siltstones, mudstones, smutty coals and parallel to poorly cross-bedded medium-grained sandstones occurs, above which the sandstones become dominant and display mudstone pebbles and log fragments on the bedding planes. This basal sequence is overlain by a 6 metre fining upward series consisting of a moderately massive, medium-grained sandstone grading upwards through tabular, to trough-shaped, cross-bedded fine to medium grained sandstones which exhibit current lineation on the foreset planes. 400 metres north-west of this locality only the Avulsion/Overbank sub-association occurs (see p. 144). In Danebower and Reeve Edge Quarries near complete sections of the Rough Rock are observable and in both cases are split into two units by a mudstone pellet band (Plate 10), both units being representative of the Flood Channel sub-association.

The pebble band is assumed to be equivalent to the pebble bands in the roadside quarry. The lower unit, although only partially exposed, is a massive-bedded sandstone but exhibits tabular, thick, medium-scaled cross-beds in which the individual cross-beds are up to 18 cms. thick and suggest deposition in a very large-scale scoop. The upper unit consists entirely of tabular medium-scaled cross-beds, in Danebower Quarry, with a slight decrease in set thickness towards the top of the unit, while in Reeve Edge Quarry trough-shaped, cross-bedded sets are developed towards the top of the unit. East of Reeve Edge at Blackclough the lower unit remains similar, though the upper unit has parallel-bedding and ripple-bedding developed between thinner tabular sets. Immediately north on Axe Edge Moor the Rough Rock forms only a slight feature and is poorly exposed, only a few metres of tabular set being visible. In the whole of the southern exposures, palaeocurrent directions are between north-west and north-east.

At Goytsclough Quarry, which lies between a thin development of parallel-bedded and weakly troughed and tabular cross-bedded sandstones on the eastern limb of the syncline and the Avulsion/Overbank sub-association in the Cat and Fiddle area on the western limb, a thick Flood Channel sub-association is developed. It is again exposed as two independent units split by an intraformational mudstone conglomerate, but to a far greater extent than the southern exposures. The lower unit is exposed from 4 metres below to 3 metres above quarry floor level, and consists of a basal medium-grained to granular massive to chaotically bedded sandstone (Plate 56) with included large blocks of shale and mudstone and log fragments, with a faint suggestion of a very steep channel wall eroding into a series of fine-grained parallel- and ripple-bedded sandstones. These are observed behind the public conveniences at the northern end of the quarry and are possibly continuous across the car park to the east of the channel, but faulting at the locality casts doubt on other possible fine-grained lateral equivalents. The unit fines upwards into a medium-grained weakly cross-bedded, massive sandstone in which both tabular and large-scale trough-shaped cross-bedding is developed. It is overlain by a mudstone conglomerate, which has a sharp, locally channelled, erosive base (Plate 12), and grades laterally into mudstone pellet bands. This horizon can be traced north to Errwood Bridge and follows the level of the road, being visible either in the streams near Goytsclough or in the road cuttings towards Errwood. At Errwood Hall smutty coals and ganisteroid sandstones exposed in the stream show comparisons with those at Danebower and are held to be equivalent. (cf. Moore, 1960, Fig. 8)

The upper unit exhibits a complete fining upwards sequence, and is at least 14 metres thick, of which the lower 10 metres is visible to the north of the stream draining Stake Clough (Plates 34 and 39), and the upper 4 metres south of the resited Goyts Bridge in road cuttings and at stream level (Plates 52 and 61). The general sequence is as follows:

Wave oscillatory ripple-bedded and parallel-bedded fine-grained sandstone with occasional thin micaceous mudstones;

Trough-shaped, cross-bedded, locally calcareous fine to medium grained sandstone;

Undulating parallel-bedded, medium-grained sandstone;

Massive-bedded, medium-grained to granular sandstone with poorly discernible large scoops and tabular, thick medium-scaled cross-bedding;

Mudstone Conglomerate.

Palaeocurrent directions in the Goytsclough area are from both the north and the south with localised incursions from the east and rare western currents.

Finally, at Issue Tor 'Quarry' a similar double unit sequence is exposed (Plate 13), which can be traced south through stream sections to Errwood Dam. The massive beds are conspicuous in that where they are thick to normal, tabular cross-beds, they exhibit current lineation on the foreset planes and locally show excellently preserved plant fragments (Plate 37). Stratigraphic equivalents of these cross-bedded fine to medium grained sandstones occur on the south-western side of Errwood Dam and by the northern abutment of Errwood Bridge (Plates 44 and 45), though at the latter locality they become pebbly. A full fining upwards sequence does not appear to develop but trough-shaped cross-bedding in medium to coarse grained sandstone exposed in Goyts Lane (Plate 51) is believed to represent a thin, lateral equivalent of the Flood Channel sub-association.

Palaeocurrent directions are from the north-west to north at Issue Tor and Errwood Dam and Bridge, while on the opposite side of the valley the direction has an easterly component.

Interpretation

There is abundant evidence supporting the fluviatile origin of the Rough Rock: formation in an oxidising environment, unimodal directions of the cross-bedding, local erosion of strongly oxidising environments, and a majority of structures indicative of deposition in the upper part of the lower flow regime. However, data from the Rough Rock are more complex than data available from modern river studies, and basic differences occur between the Rough Rock and most contemporary models and descriptions (Allen 1964, 1965, 1970, Visher 1965, Moody-Stuart 1966).

Two basic fluviatile models exist, conforming to the braided and meandering river, or low and high sinuosity river respectively.

The braided river is characterised according to Allen (1965) by an adundance of in-channel deposits formed by aggradation and crevassing being of negligible importance. However, Moody-Stuart (1966) suggests that the braided river does aggrade, becoming wider and shallower prior to abandonment by avulsion. This difference in opinion appears irreconcilable. On the one hand, where a braided river is unimpeded there is no reason why it should change course by avulsion when it can freely comb across the floodplain. On the other hand if a sudden influx of elastic material is introduced into a constricted network, or if differential subsidence/tectonic activity occurs, then the river would have to widen its existing braided channel network, prior to possible avulsion, though it is exceedingly doubtful that the whole network would shift (Coleman 1969). The end product of both mechanisms is a 'blanket sand', the vertical sequence of which is likely to be a combination of lateral and vertical sedimentation.

Internal characteristics of the braided river are typified by a trough-shaped, basal erosion surface at the base of a 'fining upward' sequence (Moody-Stuart op. cit.), a high proportion of planar cross-stratification exhibiting unimodal directional properties, which increases downstream at the expense of horizontal stratification (Smith 1970), and a high bed load/suspended load ratio (McGowen and Garner 1970). In addition, Smith (1970) noted a random vertical sequence in grain size but a fining upward sequence in the distribution of structures. He states that the important conditions for the development of a braided river are high regional slopes, abundant sediment supply and a variable discharge.

The meandering or high sinuosity river has been extensively documented (Allen 1965), and is characterised by a well developed fining upwards sequence, the presence of fine-grained top-stratum deposits, a preponderance of trough-shaped cross-stratification and ripples and a high variance of directional data for the cross-stratification when compared to the overall channel direction. Furthermore, due to ploughing of the channel across its floodplain, an extensive planar basal erosion plane may be developed if the channel is unimpeded. More commonly the channel is constricted by clay plugs and will form a new channel by avulsion, causing multi-storey channel fills with separate and distinct erosive bases but intertongued top-stratum deposits to develop.

The two basic models of braiding and meandering rarely exist in isolation, and it is more common for a combination to occur. Coleman (1969) cited the Brahmaputra River, which since the 18th Century has gradually changed its course by avulsion. The new channel commenced as a meandering channel but at the present time is extensively braided, carrying a silt and fine sand bedload and heavy suspended load. He suggests that the migration was due to a combination of tectonic activity and catastrophic floods, which are both common in the present-day regime. The present tectonic activity is proved by the occurrence of fault-scarps within the flood-plain and the recording since 1900 of twenty shallow- and intermediate-depth earthquake epicentres in East Pakistan.

Apart from the above causes, channel migration and overbank deposition are due to the instability of the bankline areas caused by the slumping of saturated fine sediment. This process is also featured in the formation of crevasse-splays which are deposited where the local regional slope normal to the main channel is high enough to allow the transport of bedload sediment over the floodplain area.

Overall, the deposits described from the lower reaches of modern rivers have a bed load of coarse silt to fine sand and an abundance of trough-shaped cross-stratification. This primary feature is the most obvious difference between the Rough Rock and any modern counterpart. It must therefore be assumed that the system which deposited the Rough Rock carried a coarser load than its modern counterpart, if any analogies are to be drawn.

In isolation, the character of the lithofacies and the geometry of the unit point to a braided model. There is a preponderance of tabular cross-bedding, and sub-regional directional trends have very little variance, while there is also a lack of top stratum deposits, and the basal erosional surface appears to be trough-shaped rather than planar. In addition, vertical decrease in grain-size is poorly developed and only the decrease in set size and increase in the trend towards trough-shaped cross-bedding can be termed fining upward.

However, when the areal distribution of palaeocurrent measurement is taken into account, the overall impression of a braided river system must be modified.

The most striking individual feature of the Rough Rock in the Southern Pennines is the diverging current data between the North Staffordshire Coalfields and the Goyt Trough. The only feasible process available is an overbank type deposition. The alternative would be a complicated depositional and erosional process involving the areally localised but vertically complete erosion of a braided river deposit by a braided river flowing from the opposite direction, followed by an equally complex depositional cycle. Neglecting the chance position of present-day outcrops, this process would involve a reversal of the regional slope, at least once and possibly twice during the Rough Rock period: an inconceivable occurrence.

Overbank deposition by way of crevasse-splays and possibly their extension into true avulsion channels would give rise to sheet sandstones composed of sediment similar in size to the main channel bedload, distributed through a breach in the levee or confining dunes of the main channel into the lower lying floodplain. The resultant sand splay displaying radiating or uni-directional internal cross-stratification depending on the size of the breach, the local slope and the angle of divergence between the splay and the channel. This type of deposition has been shown to exist in Carboniferous Yoredale sandstones by Moore (1960).

Yoredale sheet sandstones, although thinner, show a very close correspondence to the Avulsion/Overbank sub-association. The sheets, composed of cross-bedded massive sandstone, and derived from a channel sandstone, grade laterally and vertically into flaggy sandstones, siltstones and shale. Cross-bedding orientations are in all cases normal or near normal to the main channel trend and have a low spread. Hicks (1959) proved that one of the sheets was derived from the proximity of slumped sandstone, which agrees with the general form of splays cited by Coleman (1969) in the Brahmaputra, the process involved being a combination of bank collapse and local, high stream velocities through the resultant breach, causing overfolding.

The extent and shape of the splay will be governed by the length of the breach and the depth and shape of the floodplain depression into which the splay is directed. Moore illustrates a variety of sheet forms from the simple arcuate boundary to the irregular dentate boundary, and from directly opposing sheets from different channels to sheets running normal to the general direction, parallelling the host channel and filling the remaining floodplain area.

An unusual feature, peculiar to the Rough Rock in the west and south-west of the area, is the repeated development of identical sub-associations in localised areas following a break in the depositional process, even to the extent that directional properties of the sub-associations are unchanged. Only in the lower unit on the eastern limb of the Potteries Coalfield and in South Derbyshire is any difference apparent.

Overbank deposition will locally alter the relief of the flood-plain surface and later deposition will follow low areas between previous splays; only if a continuing high local slope is available in the form of flood plain lakes or subsidence features, will multi-storey deposits freely develop. However, in the Rough Rock, a break occurs in the fluviatile deposition, in which the Sand Rock Mine was deposited to the north of the study area, and a mudstone band, locally containing

Carbonicola and smutty coals, in the Cat and Fiddle area. Although a definite correlation cannot be established, it is most likely that the boundary between the upper and lower units of the Rough Rock, a contorted sandstone in North Staffordshire and a mudstone conglomerate or pellet band in the Goyt area, is an equivalent horizon. For topographical features to develop in the same locality during the deposition of a younger fluviatile phase would require a tectonic controlling influence on the location of the topographic low areas. Such an influence is indicated by opposing current directions. In the Cat and Fiddle area and the eastern limb of the Potteries Coalfield, flow is towards the major tectonic features of the Goyt Trough and the Red Rock Fault/Mow Cop Disturbance respectively, while current directions in the immediate proximity of these features parallel them.

Collinson (1967) has suggested that syndepositional topographic features associated with tectonic disturbance may account for lithofacies and palaeocurrent variations in the Roman Fell and Ashfell Sandstones, and that generally current directions would be strongly towards or parallel to the tectonic disturbance. Within the Rough Rock the character and distribution of the lithofacies point to a linear shallow lacustrine syndepositional feature associated with strong tectonic zones, towards which overbank flow was directed by high local slopes, and along which additional flow could be directed from one (Congleton Edge) or both ends (Goyt Valley).

The range of the relative strengths of the two flow systems (parallel to and normal to the feature) is displayed by the singular presence of an Avulsion/Overbank sub-association in the north part of the Potteries Coalfield, while in the Goyt area linear Channel and Flood Channel sub-associations cut through an Avulsion/Overbank sub-association. Similarly the range in strength of any one flow system is evidenced by the differing development of the Avulsion/Overbank sub-association, between Monestone and Town Head as compared with Foxt, and likewise between Stake Edge and the Goldsitch/Quarnford area. The variations cannot be accounted for by the normal lateral gradation (as between The Scours and Stake Edge) but must be dependent on the proximity of a main channel or local avulsion across crevasse-splay areas, forcing a connection with other channels or flood channels.

The position of the main channel or primary network, itself composed of both major and minor channel systems, would also govern the development of contorted sandstones. In the North Staffordshire Coalfields and South Derbyshire it must have been close by, as the lower unit has features akin to a Channel sub-association while the overriding force of upper Avulsion/Overbank unit was sufficient to cause complete erosion of the intervening mudstone sequence and complex contortions in the lower unit.

In conclusion the interpretation of the fluviatile association developed in the Rough Rock is of deposition on a high regional slope which, due to tectonics, has well developed localised high slopes and occasional complementary decreases in gradient obliquely crossing the regional slope. The resultant arenaceous sediments have the characteristics of deposition in a braided, or low to medium sinuosity, river (i.e. tabular crossing, contorted strata, trough-shaped basal erosion planes), even though a true braided river is only feasible for the primary distributive network of the Channel sub-association. Sediments deposited normal to the primary network, by the secondary network, although bearing characteristics of braided rivers, are due to a form overbank deposition towards or parallel to structurally controlled syndepositional topographic low areas.

These are being either closed (Goyt), or open (Congleton Edge, Foxt and Moneystone), in which flow could connect with a further primary system to the south.

Additional Lithofacies Associations

In the north-west and east of the area studied, where stratigraphic control is minimal, poorly exposed representatives of a Delta Top Association and Interdistributary Association occur respectively.

In the north-west of the area, between Macclesfield and Mellor, the Rough Rock has been proved by boreholes (Bollington, Shaw Farm, Rulow and Disley) to consist of massive, medium- to locally coarse-grained sandstone which may be split by thin shale partings. Unfortunately most of the outcrop evidence suggests a somewhat massive but fine to medium-grained development in which parallel-bedding and ripple-bedding are common. Exposures south of Mellor towards Capstone indicate that the 'Rough Rock' is split into two leaves; the uppermost leaf is composed of medium-grained tabular cross-beds with plant debris in occasional foreset planes, while the lower leaf has thin parallel- and ripple-bedded, fine to medium-grained sandstone, in which vertical furrows are abundant. To the east and west of Mellor, the development is contradictory. At Rowarth, massive, pebbly, medium to coarse-grained, cross-bedded and contorted sandstones overlie a poorly developed flaggy micaceous sandstone, while south-east of Marple, massive medium-grained sandstones with thick, tabular cross-beds occur. On the other hand, the Mellor outcrops show features in common with the flaggy developments at Cracken Edge, Errwood Bridge and Bilinge Hill.

The lowest 7 metres exposed at Bilinge Hill and the outcrops northwards to Lyme Park exhibit pinch and swell (Kappa) cross-stratified clean, fine to medium-grained sandstones with included plant fragments and mudstone pebbles. Both sequences show burrowing and derivation from the north and east.

Much of the problem in the north-west centres around whether the exposures are representative of the Rough Rock or the overlying Woodhead Hill Rock (Mellor and Rowarth) and underlying Rough Rock Flags (Brink

Brow and Billinge Hill). It is felt that without detailed palaeontological control or lithological control from outside the area it must be assumed that the exposures represent the Rough Rock, and that the lithofacies associations change rapidly from the south. A plausible feature when one considers the restricted Channel sub-association development at Cracken Edge, and even east to Sheffield, and the restricted nature of the coarse-grained lithofacies in the Goyt Valley.

The nature of the lithofacies and the presence of trace fossils suggest an environment akin to the deltaic plain of Coleman and Gagliano (1965), which is further supported by the occurrence of pinch and swell cross-bedding held by Allen (1963) to occur when a suspended load was being freely deposited. Due to poor exposure and stratigraphic control, little importance can be attached to this lithofacies association, but its position between two major distributive networks and close to the Red Rock Fault and Goyt points to the future need for accurate control.

In the east (Bar Brook, Holymoorside) and locally in the south (Consall) of the area, a shale and mudstone sequence with a concentration of parallel-bedded, fine-grained sandstones and siltstones, containing drifted plant fragments on the bedding planes, is developed towards the top of the Yeodonian. This sequence has been further proved by boreholes in the Derbyshire Coalfield and East Midlands Oilfields, where locally the sandstones are shown to thicken from the 3 to 4 metres at outcrop to 11 metres.

The nature of the lithofacies, although it is of very limited exposure, suggests deposition in an interdistributary environment. Local thickening of the sandstone represents shoe-string sand-bodies deposited by a random network of minor rivers, possibly controlled by avulsion or overbank flow from the primary and secondary channel to the north and south.

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Chapter 9

Conclusions

Rough Rock Sedimentation and Palaeogeography in the Tectonic Framework (Enc. 7)

The influence of the Gulf and Block elements in the E, H and R zones of the Namurian has long been recognised (Falcon and Kent, 1960), but their effect on sedimentation in the Yeadonian (G_1) and Westphalian has only rarely been considered (Kent, 1966, p.339). Similarly, the influence of features parallelling major structural zones is exhibited at Congleton Edge by strata in E, H and R (Evans *et al.*, 1968), but has not been defined in higher strata. The distribution of lithofacies associations and palaeocurrent directions in the Rough Rock suggest that both influenced the type and pattern of sedimentation by controlling the regional and local palaeoslopes and thereby restricting the development of individual lithofacies sub-associations within the fluviatile framework to zones closely associated with structural features. No study of the upper Namurian and Lower Westphalian can adequately analyse the features in isolation, and a completely integrated approach is necessary to the subtle and inter-related variations which exist.

The Rough Rock Group, of which the Rough Rock forms the uppermost 40 metres, is bounded by the *Gastrioceras cumbriense* Marine Band at the base and the Gastrioceras subcrenatum Marine Band at the top. The faunal content of both horizons has been studied in detail (Ramsbottom, 1969, and Calver, 1969, respectively), and the areal distribution of the benthonic faunal phase used to indicate the proximity of shallow water, while that of the goniatite/pectinoid fauna has been used to indicate deeper water. The distribution of the two faunal phases in the Yeadonian (G. cancellatum and G. cumbriense) shows a close relationship to the Gulf and Block development, benthonic fauna being developed on the shallow block of the East Midland Shelf and around the north edge of St. Georges Land to the protuberance of Congleton Edge at the northern extremity of the Market Drayton Causeway, while the goniatite/pectinoid fauna occurs to the north. In the Yeadonian Marine Bands the Derbyshire Block does not appear to have been a recognisable feature, although the Widmerpool Gulf east of Derby is clearly recognisable (Ramsbottom, 1969, Fig. 8). This may be due, in part, to the obvious absence of data from the eroded cover of the Derbyshire Dome, and it is of interest that Ramsbottom's boundary between benthonic and goniatite/pectinoid faunas falls along the Rough Rock outcrop between Chesterfield and Belper.

The complete dominance of the goniatite/pectinoid fauna north of the Derbyshire Block in the Central Pennines and the East and West Ridings of Yorkshire suggests that the regional slope was lower than in the Widmerpool Gulf, where the faunal incursion was restricted to a linear development as far east as Nottingham.

In the Gastrioceras subcrenatum Marine Band Calver (1969, Fig.11) demonstrates the northern edge of St. Georges Land, but no information is available to delineate the protuberance between Market Drayton and Congleton. On the other hand, the East Midlands Shelf and the Block and Gulf developments are not apparent, and the Central and Southern Pennines are covered by the deeper water goniatite/pectinoid fauna. Thus at the end of Rough Rock deposition the contrast in regional slope between the Central Pennines and the Widmerpool/North Staffordshire Gulf was no longer apparent, presumably due to the deposition of the Rough Rock. That the G. cumbriense Marine Band should exhibit greater variation may be caused by the absence of an underlying sandstone, thus amplifying the effects of differential subsidence.

In the concealed parts of the Derbyshire and Leicestershire Coalfield the source of the major distributive network is encountered, and its development is controlled by the position of the Widmerpool Gulf. At Bulcote, Cotgrave, Trowell Moor, Ilkeston and Widmerpool, boreholes proved the Rough Rock to be a coarse, feldspathic grit at least 20 metres thick, while at Ruddington and Holme Pierrepont, Nottingham, the Crawshaw Sandstone and the Rough Rock are united into a single unit. North of the Gulf the Rough Rock thins rapidly (see Kent, 1966, Plate 19) towards the Block as proved in the Cotgrave and Plungar Boreholes (see Kent, 1966, Plate 19), where it is virtually absent.

Evidence suggests that east of Derby the Widmerpool Gulf restricted the lateral development of the main channel by differential subsidence.

A braided river occupied the negative linear feature and the effects of local tectonic movement were minimal. The channel was supplied with detritus by both minor channels draining from the East Midland Shelf and St. Georges Land, and by the upstream continuation of the major channel on the Lincolnshire Shelf. There is no evidence of the source area, except areas of non-deposition and exposure of the Carboniferous Limestone in south Lincolnshire (Kent,,1966, Downing and Howitt, 1969).

In the vicinity of Derby the connection with the North Staffordshire Gulf is crossed, and the outcrop of the Rough Rock emerges from below the Westphalian and Triassic. Structural and stratigraphic control is totally lacking in this area, save for poor borehole correlation in the Ashby area, but Kent (1966 and 1967) suggests that there may be a concealed connection between Charnwood and the Derbyshire Dome based on the recognition of Uriconian type ashes and tuffs beneath the Carboniferous Limestone at Woo Dale, Buxton (Cope, 1949). If a shallow, sill-like connection is developed, this feature alone could cause a localised variation in the effect of differential subsidence at the junction of the two Gulfs. On the other hand, contemporaneous movement in Crich/Ashover or Charnian fold/fault systems would affect the sedimentation in a similar fashion. The result of both actions would be a decrease in the gradient upstream of Charnwood, causing the braided channel to increase its sinuosity.

At Coxbench the most northerly remnant of the main channel is exposed in the massive lower part of the Rough Rock, and is over-ridden by an upper unit, directed to the north, which finally fails near Ashover. The resultant feature is a crevasse-splay, possibly closely associated with an avulsion channel. That the contorted sandstones which occur at the top of the channel are caused by a combination of bank failure (the active channel may have been sited farther south), and the over-riding force of the overbank flow, is not envisaged. At Coxbench Quarry, the rapidly deposited and contorted sandstones are held to be the infilling of a scour feature associated with the main channel development.

Guion (1971) detailed a similar occurrence in the Crawshaw Sandstone, but preferred a deltaic rather than overbank causal mechanism. In the light of the close relationship with the Rough Rock in the whole of the Southern Pennines, it is felt that the Crawshaw Sandstone in South Derbyshire represents an avulsion channel derived from a major river development in the Widmerpool Gulf.

In the North Staffordshire Gulf the position of the main channel is controlled by differential subsidence of the gulf development between St. Georges Land and the Market Drayton Causeway, to the south and south-west, and the Derbyshire Block to the north-east.

The north-west boundary of the gulf has been placed (Ford, 1968) along the line (Charnian trend) of reef knoll development in the

Carboniferous Limestone, which is dependent on the presence at depth of a hinge line (Johnson, 1967), and from gravity data it extends to Whaley Bridge before curving eastwards into the southern flank of the Edale Gulf.

The southern border is far less clear. Ramsbottom (1969) demonstrates the proximity of the shore-line in the area between Charnwood and Rugeley (Ramsbottom, op.cit., Fig. 9), and at Congleton Edge (see p.160) during the deposition of the Gastrioceras cancellatum and Gastrioceras cumbriense Marine Bands. However, identification of the Rough Rock in the Bowsey Wood (Trotter, 1954) and Chartley boreholes points to protuberances along the Malvern line as well as the Church Stretton line, a feature in agreement with the generally held view of a southerly migration of crustal warping during Carboniferous times.

The derivation of the sandstones encountered in the Chartley and Bowsey Wood boreholes may be from St. Georges Land or from the Widmerpool Gulf, the latter being favoured. Rivers draining St. Georges Land deposit no sediments within the confines of the North Staffordshire Coalfields (15 miles to the north) and as such their strength would be too low to erode contemporaneous sediments. On the other hand, a distributary derived from the main channel, sweeping the northern edge of St. Georges Land to enter the Cheshire Basin through a breach in the Market Drayton Causeway, would act as a catchment to avulsion and overbank flow from the main channel. The branching of the main channel system within the

North Staffordshire Gulf is placed east of the Cheadle Coalfield.

The main channel sweeps north-westwards towards Macclesfield, and if the pattern at Derby is to be followed its sinuosity will increase on the upstream side of the tectonic features crossed, and decrease, or return to normal, on the downstream side. Similarly avulsion/overbank deposition will be most marked on the upstream side, but downstream will fade as the distance back to the syndepositional feature increases.

In the vicinity of Leek where the channel flows across the Chartley/Goyt axis (Malvernian), all the above features are developed.

At Wall Grange, the Rough Rock cuts down into the underlying mudstone and incorporates within its basal conglomerates brilliant red mudstone pebbles that suggest sub-areal exposure in the immediate area, while 3 miles due south at Consall, the Rough Rock is virtually absent. Both these localities are situated in the zone of the Shaffalong Syncline, a perfect, north-south alligned, 'U'-shaped fold which appears to have controlled the feature.

Upstream at Foxt and Moneystone, avulsion/overbank deposition occurs to the south of the channel. The nature of the deposition is two-fold, with an initial overbank phase directed towards the south-west cut by a later avulsion channel at Foxt and Whiston alligned due north-south, which is assumed to connect with the southern branch of the main channel. To the north of Foxt a similar offshoot must have existed and flowed north into the Goyt Trough, which had the form of a linear basin being at its deepest near Goytsclough Quarry.

Downstream from the Chartley/Goyt Trough line, easterly directed avulsion/overbank flow towards the Goyt Trough gradually fails. It is well-developed at Quarnford and Goldsitch where it may be purely an avulsion flow but is more likely to be a strong overbank flow due to the proximity of both the main channel and the flood channel. Farther north, generally finer-grained representatives occur as far as Stake Edge, north of which they fail completely. Apart from the likely increasing distance from the parent channel, it is probable that the lack of overbank deposition was due to the increasing influence of the Manchester Basin across the Red Rock Fault line and that the Goyt Trough was no longer preferred.

South of the main channel avulsion/overbank deposition in the Potteries Coalfield occurred in close proximity to the main channel, and was directed towards the west where it joined with overbank flow moving south-west parallel to the Market Drayton Causeway. On Congleton Edge there is no evidence of high discharge, as compared to the eastern limb of the Potteries Syncline, where complex contortions occur. It is envisaged that the depositional environment was completely sub-aqueous, which would check the high discharge and at the same time allow the deposition of suspended sediment between beds and on the foreset planes. The doubtful occurrence of contemporary volcanic sediments at Apedale (Giffard, 1923) could account for the peculiar nature of the mudstone bands at Mow Cop Quarry, but since bentonite is absent and similar deposits have not been observed close to proven volcanics on the East Midlands Shelf, deposition of suspended fluviatile sediment in oxygenated water is preferred.

North of the Derbyshire Block and East Midlands Shelf, evidence for the development of the Edale Gulf is minimal, only the occurrence of channel sandstones and a failing of the Rough Rock, to the south of the presumed southern hinge line, points to its presence. Palaeo-current data suggest that sediment was being freely transported across the Rotherham High into the Edale Gulf, but was diverted around the north of the Derbyshire Block, only a minor amount of sediment reaching the south-eastern Goyt area. The presence of red mudstone granules in the north-easterly derived sandstones in the Goyt Trough suggest that emergent areas were still present east of Whaley Bridge on the Derbyshire Block.

North of Whaley Bridge to Glossop, weak channel systems are freely developed in contrast to the strong channels in the northern and central Pennines and restricted channels in the area to the south. Nevertheless the appearance of a north-east to south-west current flow indicates that the southern boundary of the major and extensively documented distributive system to the north controls sedimentation.

On the other hand, to the west of Whaley Bridge and Glossop, the influence of the Goyt Trough is marked by a sharp southerly diversion of flow, and flood channels supplying sediment to the north of the Goyt depression are developed at Hoo Moor and Whaley Moor, both showing evidence of erosion of emergent mudstone deposits.

Petrographic data indicate a subtle difference in the clay/mica content of the sandstones deposited by the two systems. Shackleton (1962) shows that the Rough Rock derived from the north-east has an average clay/mica content of 10%, while petrographic analysis of the Rough Rock in the area of this study indicates an average content of 15%, which agrees closely with data from the Crawshaw Sandstone (Guion 1971). It is likely that this difference is due to a difference in channel gradient, or amount of suspended sediment, rather than a difference in source area.

Finally, the effect of the Goyt axis on the development of the Sand Rock Mine is apparently demonstrated in the north-west of the study area, and can be traced into the North Staffordshire Gulf.

If the present stratigraphy is correct, a major change in facies occurs to the west of the Goyt Trough in east Cheshire. It is revealed by the development of an upper and lower leaf of the Rough Rock, separated by the Sand Rock Mine (Romiley Mills Borehole) and its associated seat-earth and mudstones. On the western limb of the Goyt Syncline south of the Cat and Fiddle Inn, a Carbonicola band divides a weak development of the Rough Rock, which is held to be broadly equivalent to the coal smuts and ganisteroid sandstones at Danebower and Errwood (brackish water conditions in the floodplain area compared to plant growth on the surface of the abandoned flood channel). Following rejuvenation, much of the sequence was eroded and incorporated into a basal mudstone conglomerate of the upper unit, the lower boundary of which is held to represent the pause in elastic deposition. In the Potteries Coalfield the pause is identified by the erosive junction between the contorted sandstones and the overlying tabular cross-beds, and by the mudstone bands at Congleton Edge. The eastern limit of this feature is not visible but the absence of clearly developed twin units and the absence of any Carbonicola horizon in the interdistributary areas leads one to speculate that the Chartley/Goyt axis acted as a barrier.

Regional Appraisal

The importance of the virgation of folds and faults centred on Macclesfield has long been recognised (Fearnsides, 1933, and Turner, 1949), and movement on any one trend would activate the neighbouring trends and the chance of semi-continuous activity in the area would be high. The results of this study suggest that the major activity was Malvernian, as displayed by movement along the Chartley Axis and Goyt Trough.

During the upper Carboniferous, epeirogenic movements spread southwards from the North of England, and during deposition of the Rough

Rock were most pronounced immediately to the north of St. Georges Land.

Flow was therefore directed from the east through the Widmerpool and North Staffordshire Gulfs, to converge from the south-east on the Manchester Basin, where it encountered flow derived from the north-east, north and west.

This pattern survives into the Crawshaw Sandstone/Woodhead Hill Rock, being only slightly modified north of the Derbyshire Block, and at similar horizons in South Wales (Bluck, 1961, and Bluck & Kelling, 1967) and the Ruhr (Pilger, 1948). These features point towards a period of tectonic influence in the areas immediately adjacent to St. Georges Land bringing to a climax the Millstone Grit type deposition.

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